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DEVELOPMENT OF DESIGN CRITERIA FOR STEEPLY DIPPING FOOTWALL STABILITY IN MOUNTAIN REGIONS (UP-H-221)

FINAL REPORT

BY

HARDY ASSOCIATES (1978) LTD.
BURNABY, B.C.

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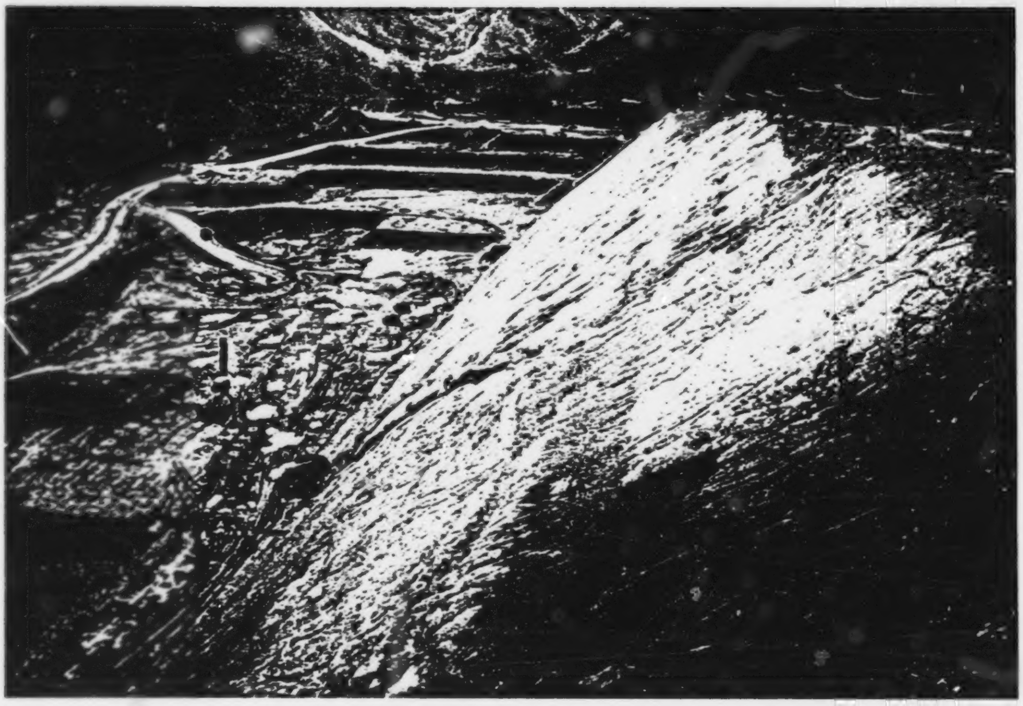

A typical open pit coal mine footwall, exhibiting overall slight convexity together with a minor depositional roll feature causing local slabbing instability - Line Creek Mine, near Sparwood, British Columbia, operated by Crows Nest Resources Ltd.

SUMMARY

This study was conducted to investigate the factors affecting steeply dipping footwall stability in mountain regions, and to determine appropriate design criteria.

Using geotechnical data collected from the footwall at the Line Creek Mine, Sparwood, B.C., this study has investigated exploration techniques, monitoring methods, analytical design methods and design implementation and operational constraints. The critical parameters for the stability of a footwall have been identified, and innovative methods of analysis have been developed, particularly with regard to the analysis of buckling failure of curved slabs.

The design criteria developed as part of this study have been applied to the situation at the Line Creek Mine, and have demonstrated that the footwall at this location is in a state of conditional stability.

Finally, recommendations have been formulated to ensure the optimization of exploration data, monitoring data, analytical processes and their implementation at any open pit mine in mountain regions.

Significant developments which have occurred in the course of this project include the following:

a) Writing of program CURVBUK which offers the first practical methods for analyzing curved slopes subject to buckling.

b) Further development of analytical methods for analyzing plane slopes subject to buckling.

c) First in situ stress measurements in a surface coal mine in the Rockies. These measurements confirm the presence of high horizontal stress.

d) Detailed monitoring of footwall movements to provide a reference data base. No other similar measurements are presently available.

e) Development of design stability charts for various stability modes.

f) A comprehensive examination of the present state of the art in footwall design.

g) Presentation of the various stability and monitoring methods available for footwalls.

SOMMAIRE

Cette recherche a été conduite sur l'étude des factuers affectent la stabilité du plancher inferieur á forte inclinaison en regions montagneuse, et de determiner les critères de planification appropriés.

En utilisent les données géologique recueilie du plancher inferieur á Line Creek Mine, Sparwood, B.C., cette étude a examiner les techniques d'exploration, methodes d'enregistrement des données, l'étude analatique des methodes de planification et l'accomplissement des limites d'operation. Les paramétres critique pour la stabilitér du plancher ont été identifie, des methodes inovative d'analysé ont été developpées, particuliérement pour l'analyse des ruptures des couches courbée.

Les criteres de design dévelopés au cours de cette étude. On été utilisés á Line Creek Mine, et ont dé montré que la couche inferieur á cette location est dans un état conditionnel de stability.

Finallement, des recommendations ont été formulés pour l'utilisation optimal des données d'exploration, des données d'euregistrement, de l'analyse et pour l'application á n'importe quel mine á ciel ouvert de region montagneuses.

Dévelopments significatif son survenu au cours de ce projet:

a) L'invention d'un program CURVBUK qui offre des methodes pratiquent sur l'analyse des couches courbée sujetes á rupturer (buckling).

b) Au dévelopment plus poussé des méthodes analytique pour l'étude des couches incliner normal sujete á flamber.

c) La premiere recherche analytique fait sur place dans une mine de charbon dans les Rockies pour mesurer la tension. Ceci a confirmer la presence de forte tension horizontal.

d) Étude détailer du mouvement de la couche pour donner des données de référence. Aucune recherche similaire n'est presentement disponible.

e) Le development de graphique pour le design de stabilité pour différent mode de stabilité.

f) L'étude compréhensif de l'état present du plancher et de son design.

g) La présentation de diverse stabilité et des méthode de controler les planchers.

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APPENDIX 'B' Details of Computer Program CURVBUK - Comprehensive Analysis of Buckling of Curved Slabs

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1.0 INTRODUCTION

1.1 TERMS OF REFERENCE

Terms of reference for this study are outlined in an unsolicited proposal entitled "Development of Design Criteria for Steeply Dipping Footwall Stability in Mountain Regions" submitted by Hardy Associates (1978) Ltd., Burnaby, B.C., in January, 1985, to the Director General, Science Centre, Department of Supply & Services, Hull, Quebec. This proposal was accepted, with slightly modified funding, on January 23, 1986, with the signing of Contract Serial No. 1SQ85-00295 (Requisition No. 23440-5-9221, Financial Code 234-131-000000-202803-0415).

1.2 SCOPE OF REPORT

This report is the result of a study of a serious potential instability condition that is developing on surface coal mining projects in the western mountains of Canada. Many of the surface coal mines are encountering steeply dipping footwall conditions. As the footwall becomes higher, the danger of failure by buckling or shear through the footwall increases considerably. Failure could be induced by stress exceeding rock strength, exposure of secondary discontinuities through the footwall rock, high pore water pressures or damage due to blasting.

Maximum slope heights at the present time are in the order of 100 m. However, a number of mines have plans to expose up to 500 m of footwall. These high proposed slopes could be unstable, and may require costly mitigative measures to avoid the sterilization of an appreciable volume of coal reserves.

This report endeavours to provide investigative and design procedures to evaluate and solve this problem.

The proposal outlined the following tasks to be undertaken:

a) TASK 1: Field work to determine base geological engineering parameters for the design of footwalls.

b) TASK 2: Trial of methods to detect geometrical problems (rolls, faults) during mining, in sufficient time to allow stabilization.

c) TASK 3: Development of kinematic failure models.

d) TASK 4: Development of stability analyses models.

e) TASK 5: Development of stability design charts.

f) TASK 6: Development of stabilization methods and design criteria.

g) TASK 7: Development of monitoring methods.

These tasks have all been completed and are reported in discussion of the following aspects:

- elements of footwall design;
- exploration considerations and techniques relevant to footwall design;

- monitoring techniques required to determine footwall characteristics on an ongoing basis;
- the development of innovative analytical design methods to determine footwall stability;
- design implementation methods and operational constraints;
- analysis of the overall stability of the Line Creek Mine footwall, as a case history example of the implementation of the recommended techniques;
- conclusions and recommendations relating to footwall stability and its determination.

1.3 PERSONNEL

This study was completed by the following personnel:

- D.S. Cavers, M.Eng., P. Eng. - Project manager and technical director.
- G.J. Baldwin, M.Sc., P. Eng. - Field work, case history and general technical input.
- M. Goldbach, E.I.T. - Computer analyses.
- C.O. Brawner, P. Eng. - Review and specialist consultant.
- R. Bertinshaw, P. Eng. - Formerly Chief Mining Engineer, Crows Nest Resources Ltd., logistics assistance.
- T.W. Hannah - Senior Geologist, Crows Nest Resources Ltd., field work assistance and monitoring.
- M.A. Stoakes - International Mining Services Inc., in situ stress measurement.

In addition, other support staff were drawn from personnel working for Hardy Associates (1978) Ltd. and Crows Nest Resources Ltd.

1.4 FIELD WORK

Initial field work at Line Creek was undertaken between April 14, 1986 and May 3, 1986. This work included the following:

a) Installation of two slope indicator casings in the footwall.

b) Installation of two extensometers perpendicular to the footwall extending to a depth of 15 m.

c) Installation of pneumatic piezometers in 3 holes.

d) In situ stress measurements in 1 hole.

e) Air track drill holes to determine seam geometry.

Assistance and material support was provided by personnel from Crows Nest Resources Ltd., Line Creek Mine. The drilling was subcontracted to Drilcor Industries Ltd., while International Mining Services Inc. provided personnel to complete the in situ stress measurements.

Ongoing monitoring since installation of the field instrumentation has been undertaken by Line Creek Mine personnel, assisted at times by Hardy Associates (1978) Ltd. Although a few problems have arisen, the installed instrumentation continues to function well on the footwall slope, and no unrepairable blast damage has yet been encountered.

1.5 ELEMENTS OF FOOTWALL DESIGN

Footwall slopes in open pit coal mines are formed by the strata underlying the coal seam exposed as the mine is deepened. While the design methods developed in the course of this project are specifically addressed to open pit coal mines, they are not limited to sedimentary strata, and could be applied to other situations, such as sheeting joints in granite, joint-bounded rock columns in sandstone or to blocky granitic rock masses subject to high in-plane stresses.

Footwall design is an ongoing process, even more than highwall design, since not all parameters can be adequately determined during the preproduction stages. Typically, the process starts with delineation of the deposit by drilling. However, this preproduction drilling normally does not fully define small scale features which may cause problems during mining. Therefore, the process of actually mining a footwall is an ongoing one, consisting of updating information on geometry and applying mitigative measures, as required, to maintain stability of the footwall as the pit is deepened.

In Western Canada, the practice has been to mine footwalls with as few benches as possible. In fact, walls with slopes up to 85° have been mined to heights of 100 m or more, while footwalls with dips in the order of 40 to 45° have been mined, or are planned, to heights in excess of 400 m.

Features tending to cause instability in footwalls fall into two categories:

1) Large scale features, including the overall curvature of the wall, which set an upper bound to stable height without benching.

2) Small scale features, such as small rolls, cross faults, unfavourable joints or bedding pinchouts, which may cause problems during mining, and should be dealt with on an ongoing basis by mitigative measures.

Small scale and large scale features may both trigger either buckling failure or translational failure. These different failure modes are discussed in greater detail in Chapter 4; however, it should be noted that either mode can produce fast moving failures which can produce hazardous conditions for personnel working in the pit. In addition, buckling failures may give little warning prior to failure.

Footwalls are unusual in that failure of footwall slabs of large extent can be precipitated by relatively small features which may be difficult to detect during mining, and impossible to detect at the initial exploration stages. This, combined with consideration of the various failure modes, suggests that the optimal design process is one of continual feedback during mining to allow adequate mitigative measures to be undertaken for whatever geometrical features are encountered.

This process of continual feedback and revision of the design has been previously proposed and documented by Peck (1969). This so-called "observational" method essentially involves the following elements:

a) Establish an initial design on the basis of premining geometry and geotechnical data.

b) Investigate the range of failure modes which could be reasonably expected to occur, and which cannot be detected by the premining exploration program. This might include the determination of maximum roll radius, change in dip of roll, cross faulting of certain maximum amplitudes, or the magnitude of bedding pinchouts. The list of possible problems which could be encountered will be different for each mine, and input from the structural geologist and exploration geologist is of great importance.

c) At the premining stage, develop possible solutions to various problems that might occur. It is not necessary to complete the design to the various alternative solutions; however, various alternatives should be checked in sufficient detail to provide reasonable assurance that they will be feasible and economic.

d) During mining, observation of features on the wall and exploration below the pit floor are used to update the geometric model of the footwall. Monitoring provides feedback on movements and stability of the wall, allowing the performance of the wall to be assessed on an ongoing basis.

e) As problem areas are detected during mining, mitigative measures are undertaken where necessary to stabilize the wall.

This process of ongoing updating of design and undertaking of mitigative measures continues until the wall is completely excavated.

The following chapters of this report discuss the various elements required for implementation of the observational method on footwalls. A significant part of this report is the discussion of new analytical methods developed in the course of this work to provide reasonable analytical solutions for the various geometries of footwall problems which may be encountered in practice. This includes development of program CURVBUK, copies of which have been provided by Hardy Associates to CANMET. We recommend that this program be available through CANMET at cost of materials. Hardy Associates is also prepared to provide copies at cost.

2.0 EXPLORATION CONSIDERATIONS AND TECHNIQUES

2.1 INTRODUCTION

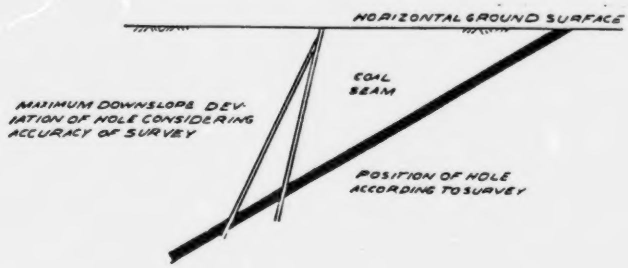
This chapter briefly considers various possible methods to acquire basic geologic and geotechnical information for a planned footwall. The chapter concentrates on special methods which may be used, but also discusses some conventional techniques insofar as their accuracy affects conclusions with respect to pit geometry.

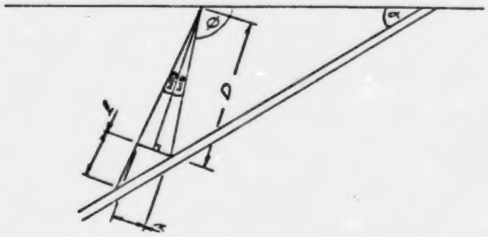
As mentioned in Chapter 1.0, footwall stability is sensitive to minor variations in geometry, structural geology, hydrogeology and in situ stress conditions. The aim of the exploration program should be to reduce these uncertainties as much as possible.

2.2 GEOMETRY AND GEOLOGY

2.2.1 Drilling Accuracy

As shown in Figure 2-1, a drill hole intersecting an inclined seam is greatly affected by minor variations in hole orientation, particularly for deeper holes. The formula shown in Figure 2-1 may be used to calculate typical uncertainties for deeper holes which might be considered during exploration. Using an accuracy of ±1° in dip orientation (typical of the system accuracy of many downhole probes), an uncertainty in the location of a coal seam of up to 6 m in a 150 m hole could be encountered. The only methods available to improve this accuracy using conventional techniques are as follows:


HORIZONTAL GROUND SURFACE
COAL SEAM
MAXIMUM DOWNSLOPE DEVIATION OF HOLE CONSIDERING ACCURACY OF SURVEY
POSITION OF HOLE ACCORDING TO SURVEY


ϕ
α
$\frac{\theta}{2}$
$\frac{\theta}{2}$
D
ℓ
x

$\ell + D$ = ACTUAL DEPTH TO COAL IN DRILLED HOLE

D = DEPTH TO COAL FOR HOLE IN POSITION SHOWN BY SURVEY

ℓ = DIFFERENCE IN DEPTH TO COAL IF DRILL HOLE IS ASSUMED TO DEVIATE DOWN DIP BY THE ACCURACY OF THE HOLE SURVEY

α = DIP OF COAL SEAM

ϕ = ATTITUDE OF HOLE AS SHOWN BY SURVEY

θ = ANGULAR ERROR OF SURVEY

NOTES:
1) SURVEYED HOLE ASSUMED TO BE LINEAR
2) CALCULATION IS FOR MAXIMUM POSSIBLE ERROR IN DEPTH TO COAL SEAM

$$x = 2D\sin\frac{\theta}{2}$$

$$\frac{x}{\sin(180-\phi-\alpha-\theta)} = \frac{\ell}{\sin(\phi+\alpha+\frac{\theta}{2}-90^\circ)}$$

$$\text{OR}\quad \frac{x}{\sin(\phi+\alpha+\theta)} = \frac{\ell}{-\cos(\phi+\alpha+\frac{\theta}{2})}$$

$$\ell = -\frac{\cos(\phi+\alpha+\frac{\theta}{2})}{\sin(\phi+\alpha+\theta)}\,x$$

$$= -\frac{\cos(\phi+\alpha+\frac{\theta}{2})}{\sin(\phi+\alpha+\theta)}\,2D\sin\frac{\theta}{2}$$

EXAMPLE:

FOR $\phi = 90^\circ$
$\theta = 2^\circ$
$\alpha = 45^\circ$
$D = 150\text{m}$
$\ell = 5.5\text{m}$

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FIGURE 2-1
UNCERTAINTY IN SEAM LOCATION DUE TO UNCERTAINTY IN BOREHOLE DEVIATION
(AFTER CAVERS, 1978)

SCALE NTS	DATE SEPT/86	MADE MG	CHKD. GJB	JOB: VGO 3957	PLATE

HT12 - 79/05

a) Drill holes which are perpendicular to the coal seam. This tends both to reduce the degree of borehole deviation, and reduce the effect of minor variations in dip or dip azimuth on the depth of the coal seam.

b) Use more accurate borehole orienting tools. Tools with an apparent resolution of better than 1° are commercially available. However, the system accuracy is still limited by the length of the probe, and by the relative error between the probe axis and the borehole axis, due to variations in the way the probe traces the hole wall.

In spite of the efforts made to reduce the level of uncertainty of the location of the footwall, appreciable uncertainty will still remain at the end of the exploration stages. The formula shown on Figure 2-1 may be used to assess the maximum deviations and roll/fault geometries which could go undetected at the end of exploration stages considering borehole spacing, location and system inaccuracies.

Additional considerations include the following:

a) Borehole collar reference elevations should be surveyed as accurately as possible.

b) Footwall intersection depths on core should be checked using down hole geophysics in order to account for core expansion and/or errors by the drillers in depth measurement.

c) Some holes should be continued at least 20% of the footwall height below the footwall/coal interface to check for deep aquifers or unusual conditions.

2.2.2 Electromagnetic Tomography

Recent studies using computerized axial tomography techniques (CAT-scan) have shown promise, and the technique could be applied between boreholes penetrating the coal seam.

The basic technique, outlined in Coal Age (1986), is based on transmission of radio frequency signals between, in this case, two boreholes penetrating the coal seam. Due to the difference between the electrical characteristics of the coal seam and the surrounding rock, the seam tends to act as a waveguide for the transmitted signals. Areas of nonhomogeneity in the coal seam, whether due to sandstone channels cutting the coal seam, cross faults or coal pinchouts, increase to attenuation rate of the received signal, and may also cause reflection of the signal back towards the source.

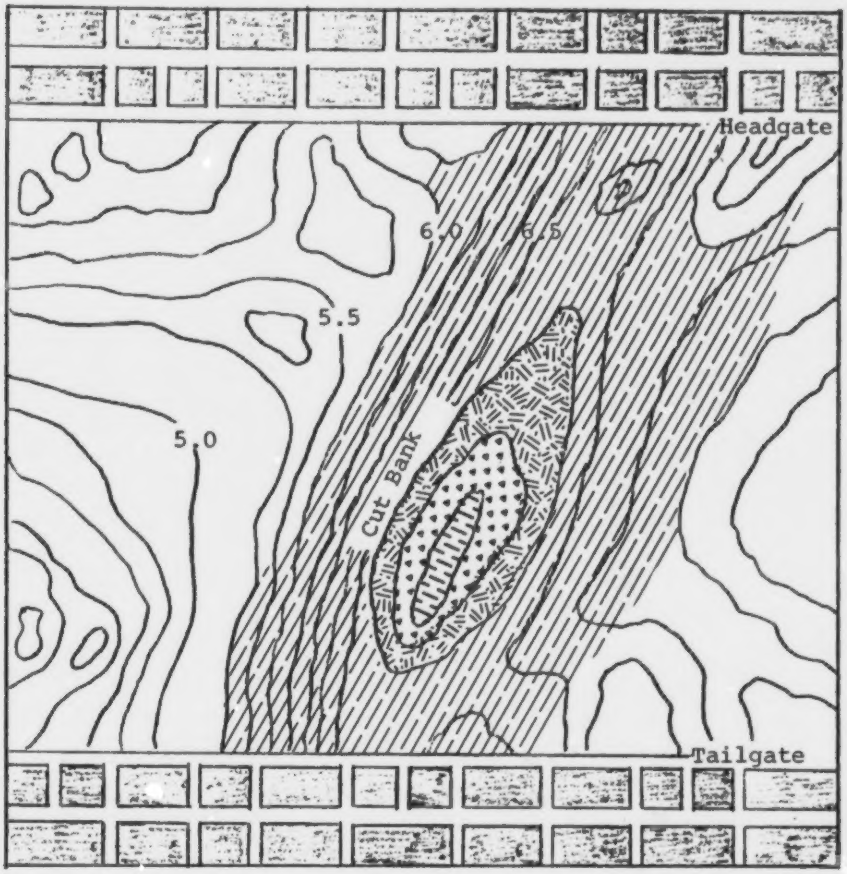
It should be stressed that the technique does not examine directly the footwall characteristics, and a number of potential footwall problems may not be detected. However, on footwalls in which cross faulting may produce stability problems, the method could be used to provide some indication of the existence of large amplitude cross faults. In this case, areas of high attenuation would be identified as possible problem areas to be watched during mining, and could be examined in more detail once mining is underway. The use of this system to detect rolls or load casts in the footwall strata is not recommended, since these features may or may not change the attenuation rate.

It should also be noted that in order for a cross fault to cause a high signal attenuation rate, the displacement of the fault must be a substantial proportion of the coal seam thickness. Thus, for a 2 m seam, the minimum fault displacement which might be detected would be in the order of 1 to 1.2 m. Figure 2-2 shows an example of an attenuation chart showing a sandstone channel cutting across a coal seam. In order to generate this type of chart for an open pit, a large number of boreholes to permit the generation of numerous different transmission paths would be required.

2.2.3 Geological Mapping of Depositional Features

The mapping of depositional features can provide extremely useful data to enable the selection of appropriate analytical design methods. This section briefly examines the geologic basis for some of the geometrical anomalies which sometimes occur on footwalls, particularly those which result in daylighted bedding surfaces. It is considered that more detailed mapping and classification of the sediments would allow a better understanding of the depositional environment and should, at least in some cases, allow predictions of the possibility of different features and their location or trend.

Much of the coal deposited in Western Canada appears to have been produced in coastal swamps or marine deltas. For the most part, this environment was characterized by substantial accumulations of peat, which, under still water and anaerobic conditions and the process of diagenesis, become coal. These periods of slow peat accumulation were periodically interrupted, allowing the deposition of mudstones and sandstones which form the hanging wall and footwall of the coal seam, as well as forming partings within the coal seams.



LONGWALL PANEL SURVEY:

Computerized Axial Tomography (CAT) Scan

Contours of constant attenuation rate (db/100ft.)

▨ 100% - 80% of Seam Remains

⁘ 80% - 30% of Seam Remains

☰ 30% - 0% of Seam Remains

▧ Sandstone Roof Rock

☐ Mudstone Roof Rock

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FIGURE 2-2

EXAMPLE OF ELECTROMAGNETIC TOMOGRAPHY
ATTENUATION CHART (AFTER STOLAR INC.)

SCALE NONE | DATE OCT/86 | MADE EU | CHKD. GJB | JOB: VG03957 | PLATE

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There appear to be two general categories of sediment depositional features which may give problems on footwalls. These are:

a) Features related to differential compaction, soft sediment slumping or similar mechanisms.

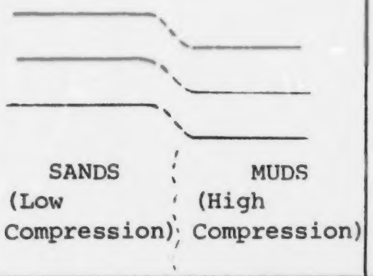
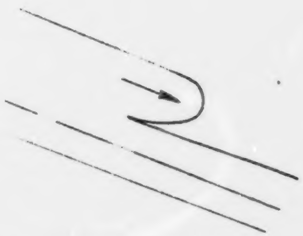
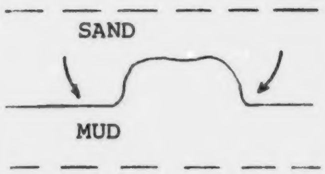
b) The occurrence of erosional or depositional features within or adjacent to the coal seam.

Table 2-1 shows a selection of sedimentary consolidation features which may lead to daylighting of bedding planes in a footwall. All of these features have been observed in Western Canadian mines. These features are less predictable in terms of existence or trend than depositional and erosional features.

Differential compaction/consolidation occurs when a sedimentary unit is draped over materials which undergo different degrees of compaction during lithification. Dip changes or discontinuous beds may occur, either on a small or large scale. Many examples seen in Western Canada occur as a result of pinchout of mudstone strata underlying sandstone.

Sedimentary slumping is not a major cause of footwall problems in Western Canada, possibly due to low energy of deposition or subdued topography in the coal basin. Load casting of sediments has been proposed by various investigators as a major cause of some anomalies on footwalls in the Hinton area.

TABLE 2-1: SOFT SEDIMENT FEATURES

SCHEMATIC DRAWING	NAME	MODE OF FORMATION	REMARKS
 SANDS (Low Compression) MUDS (High Compression)	Differential Compaction.	Variation in compressibility of sediments.	Eg. Hughes (1984).
	Sediment Slumping.	Sliding of deposited sediments - Eg. on delta.	
	Load Cast.	Heavy sand deposited on plastic mud squeezes the mud into a variety of deformed shapes. Often small scale, but large scale may occur.	May be combined with differential compaction.

Depositional and erosional features, shown on Table 2-2, tend to have limited lateral continuity and their presence and orientation may be predictable.

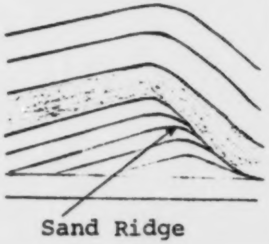
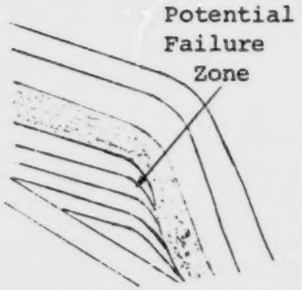
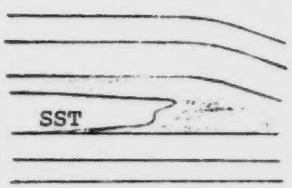
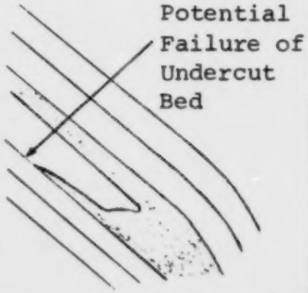
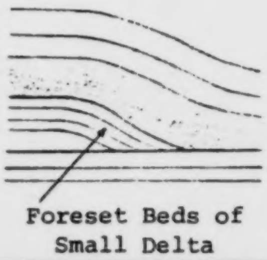
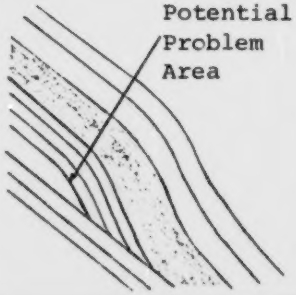
Sand ridges were common near shore features during the Cretaceous period (eg. Swift and Rice, 1984) and may have been over-run by peat and organic deposition. The ridges tended to migrate and may, at times, be underlain by coal. Two parallel footwall rolls at Line Creek which trend diagonally across the footwall may be the result of sand ridges. Similar features may be produced by sand dunes, and detailed study of cross bedding would be required to separate these features. Sand dunes might have a higher areal density and be less continuous.

Crevasse splays are formed when streams break out of channels and deposit sand. Similar lenses may be formed by currents or stream channels. The edge of the feature may overlie coal and is a potential footwall failure zone. Depending on the original geologic regime, and subsequent folding, the edge may point up, down or across dip. The down dip direction may cause stability problems.

Deltas, or other features causing pinchout of bedding, have been observed on footwalls in southwestern B.C. Translational failures have been known to occur on these features.

The foregoing examples do not cover all possible mechanisms. However, by understanding the detailed depositional environment, a great deal can be done to predict possible problem areas and mechanisms, allowing suitable mitigative measures to be planned. Significant improvements in wall stability could result.

TABLE 2-2: DEPOSITIONAL AND EROSIONAL FEATURES

SCHEMATIC DRAWING	AFTER FOLDING	NAME	MODE OF FORMATION	REMARKS
	 Potential Failure Zone	Sand ridge.	Offshore sand ridge overrun by peat deposits.	-Trend predictable. -Similar configurations may result from dunes. -Common in coal environments in Western Canada. -See Tillman & Siemers (1984).
	 Potential Failure of Undercut Bed	Crevasse Splay.	Breach of natural levee on stream through swamp allows deposition of a lenticular sand body.	-Similar features can result from point bars, small deltas & turbity currents. -See Ethridge et al (1981).
 Foreset Beds of Small Delta	 Potential Problem Area	Delta.	Lateral pinchout of beds.	

2.3 HYDROGEOLOGY

2.3.1 In Situ Permeability

Packer injection tests should be run in selected holes and formation intervals, in order to determine the in situ permeability of different horizons in or below the footwall. The test consists of running a falling, rising or constant head permeability test within a defined interval. Various packer configurations are possible to define the interval; in this study, the straddle packer arrangement shown in Figure 2-3 was used with a 3.3 to 6.3 m perforated pipe between the two packers.

The inflatable rubber packers are readily available; Photograph 2-1 shows an inflatable packer built by R.S. Technical Instruments of Vancouver, B.C. Various other configurations of packers are possible, including use of a single packer to seal the zone between the packer and the bottom of the hole, or a triple packer arrangement in which the drill string is used to provide fluid head to the formation.

Whatever the configuration chosen, the hole interval selected for testing should be washed to remove mud and mud cake, which could reduce the borehole wall permeability. The equipment allows several tests to be run in a single hole, and results can be obtained relatively quickly. The permeabilities obtained will vary with fracture frequency and lithology; however, the nature of the test allows several measurements to be made which will give an indication of variation of permeability at different locations. A summary of falling head test terminology is presented in Figure 2-4. Hvorslev

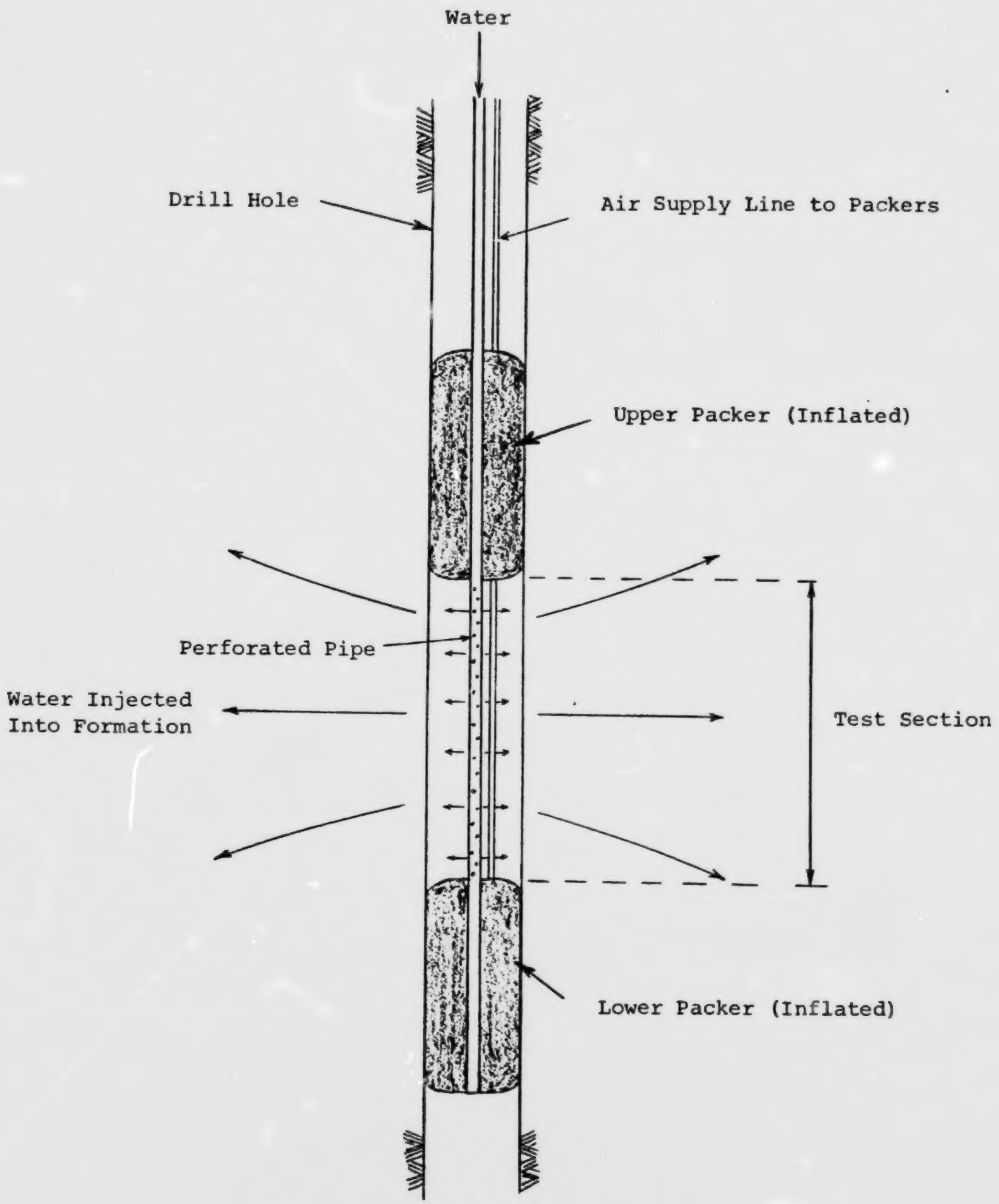

Water
Drill Hole
Air Supply Line to Packers
Upper Packer (Inflated)
Perforated Pipe
Water Injected Into Formation
Test Section
Lower Packer (Inflated)

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FIGURE 2-3
SCHEMATIC PACKER ARRANGEMENT

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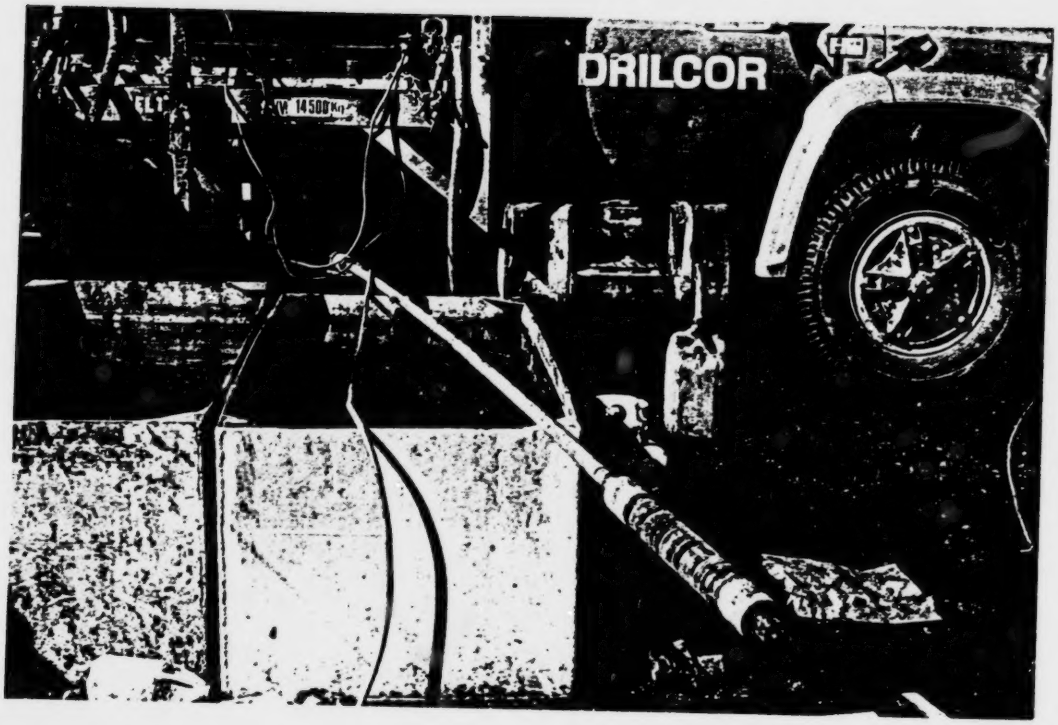
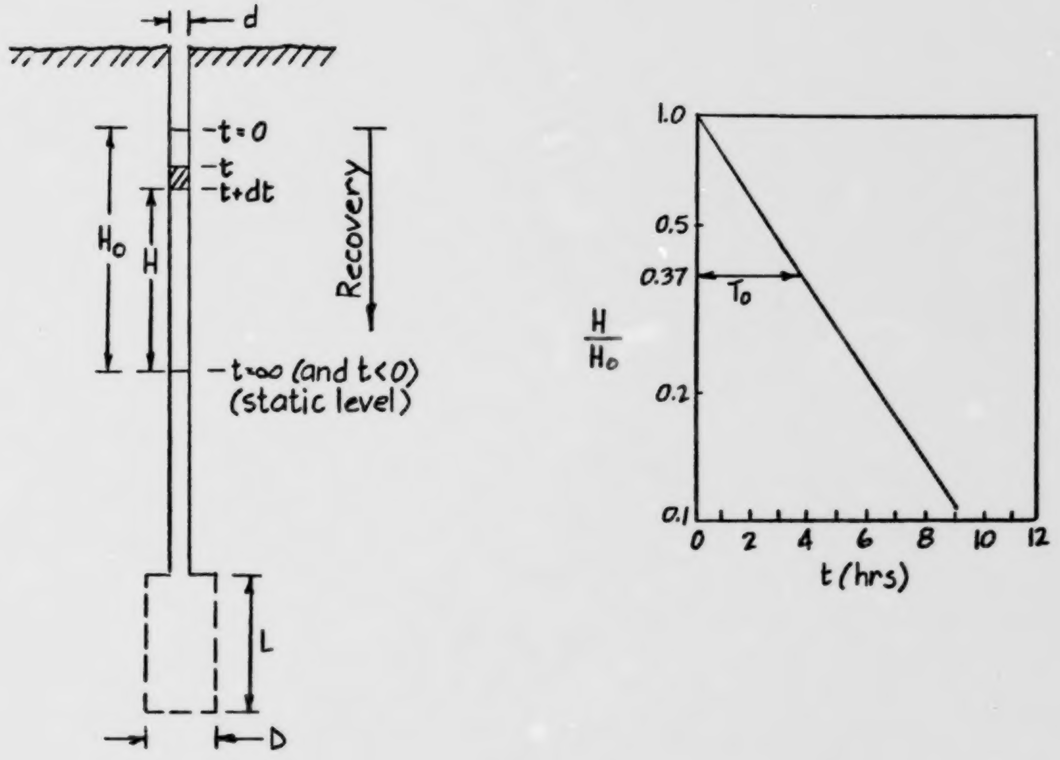
JOB: VG03957
PLATE


DRILCOR
14500 Kg


d
t=0
t
t+dt
H_o
H
Recovery
t=∞ (and t<0)
(static level)
L
D
1.0
0.5
0.37
T_o
$\frac{H}{H_o}$
0.2
0.1
0
2
4
6
8
10
12
t (hrs)

$$k_h = \frac{d^2 \log_e \left[\frac{mL}{D} + \sqrt{1 + \left(\frac{mL}{D}\right)^2} \right]}{8\,L\,T_o}$$

where $m = \sqrt{\frac{k_h}{k_v}}$

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FIGURE 2-4
FALLING HEAD TEST TERMINOLOGY

SCALE NONE
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CHKD. GJB
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PLATE

(1951) and Winterkorn and Fang (1975) provide details of the theory and calculations for packer permeability testing.

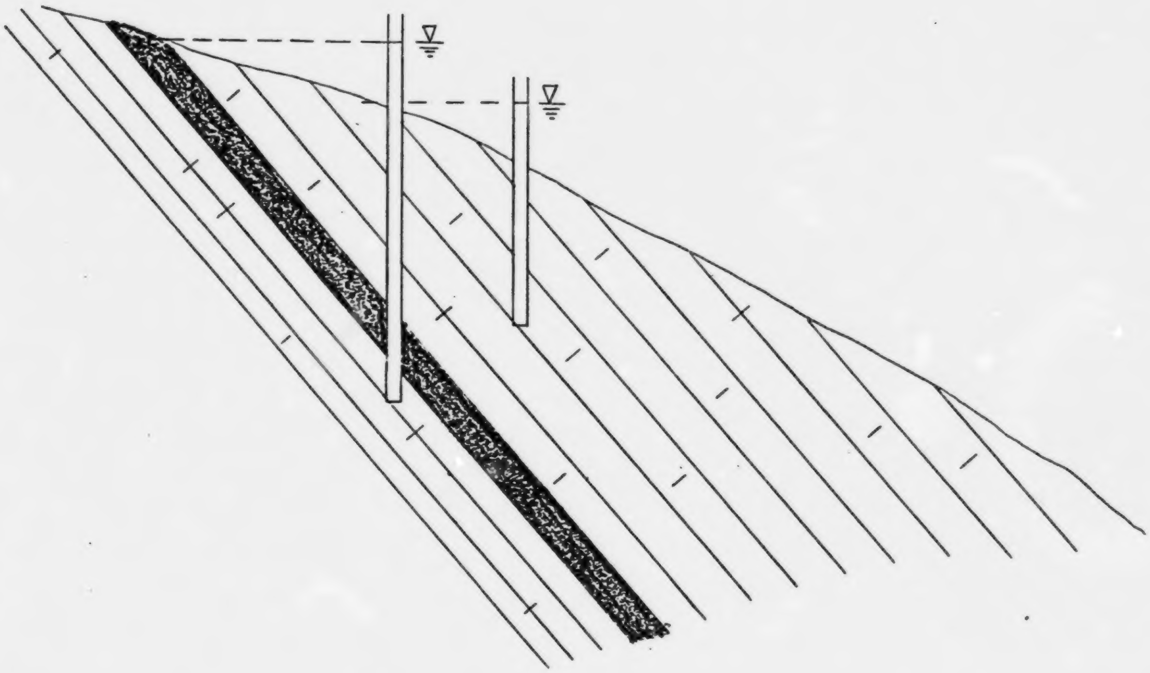
2.3.2 Instrumentation

Instrumentation installed to monitor hydrogeological conditions will principally consist of piezometers. Installation of piezometers at Line Creek behind the footwall and below the existing pit floor and the response of these piezometers is documented in Chapter 6.0. In general, the following results are expected for footwall piezometer installation (Figure 2-5):

a) Water pressure conditions prior to mining are typically artesian with respect to the footwall, and the piezometric surface may correspond approximately to the elevation of the crest of the wall. These water pressure conditions are unacceptably high for the final footwall, and monitoring should be used to check for dissipation as mining proceeds.

b) Special attention should be paid to any unusually high pore pressure conditions existing in high permeability strata behind the footwall, particularly if these strata are sealed by relatively impermeable layers closer to the footwall surface. Under these conditions, large volumes of water could maintain high pressure conditions behind the footwall, and extra measures to dispose of this water following drainage from the footwall may be required.

c) Where several coal seams exist, different water pressure conditions may occur within any of the coal seams or inter-



Measurements should only be made using piezometers sealed in the formation. Fast acting (low volume displacement) piezometers will be required for low permeability materials.

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FIGURE 2-5
TYPICAL ARTESIAN CONDITIONS
ON FOOTWALL

SCALE N.T.S.	DATE 09/86	MADE MG	CHKD. G.J.B.	JOB: VG03957	PLATE

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mediate strata, and piezometers at several locations will be required. Based on work to date on several different footwalls, it is not necessary to have large numbers of piezometers within any horizon, since water conditions along a particular stratum are often predictable.

In relatively low permeability horizons, the more conventional Casagrande-type piezometer may have a very slow response time to water pressure changes due to the volume of water required to enter the piezometer tip. Under these conditions, rapid-response piezometers, such as pneumatic or electrical ones, are recommended. Pneumatic or electrical piezometers can also be read from the top or bottom of the slope. For this study, pneumatic piezometers were installed at the Line Creek Mine.

The one major advantage of Casagrande-type piezometers is the ongoing ability to retest for permeability data, using either falling, rising or constant head methods.

2.4 IN SITU STRESS STATE

Knowledge of the in situ stress state can allow differentiation between insignificant minor stress relief movements and movements indicating deteriorating stability of the footwall. This was found to be possible at the Line Creek Mine (see Chapter 6.0). In particular, at Line Creek, it was found that the footwall slabs were "clamped" by high horizontal stresses acting perpendicular to the plane of the slab. This allowed small fractures in the slab to remain open until the high horizontal stresses were relieved by excavation, at which time the slab relaxed downwards along the bedding, closing up the small fractures. This mechanism is discussed further in Chapter 4.0.

A number of methods for determination of in situ stress have been developed (Goodman, 1980). In the course of this study, a number of these techniques were evaluated for use on footwalls. Table 2-3 summarizes the results of these investigations.

The CSIRO Triaxial Hollow Inclusion Stress Gauge, manufactured in Australia under Australian Patent No. 496712, was selected for use in this study. Figure 2-6 shows the layout of the gauge, which consists of nine strain gauges in three rosettes, encased within an epoxy shell attached to a readout cable. The field procedure for stress measurement is outlined in Figure 2-7. The hollow plastic inclusion shell is cemented into the borehole using epoxy resin. The strain relief of the borehole wall during and following overcoring is used to calculate the full three dimensional stress tensor, based on elastic rock properties determined from non-destructive biaxial testing of the overcored sample.

Use of the gauges is covered in a manual produced by CSIRO (undated). Results of this study at Line Creek are presented and discussed in Appendix 'A', while the application of these results to the footwall at Line Creek is discussed in Chapter 6.0. Installation and overcoring of the stress cell at Line Creek are shown in Photos 2-2 through 2-10.

TABLE 2-3: POSSIBLE METHODS FOR THE DETERMINATION OF IN SITU STRESS IN FOOTWALLS

METHOD	DESCRIPTION	ADVANTAGES/DISADVANTAGES	REFERENCES
USBM Gauge	Removable insert for overcoring. Determines diametrical changes of hole.	1) Requires 2 non-parallel holes for complete stress tensor. 2) Difficult to set. 3) Can be used at moderate depth.	Bickel (1985)
Flat Jack	Hydraulic jack (2 steel plates welded together) used to force walls of a slot cut in rock back to original location. Force allows calculation of stress.	1) Surface only. 2) Inexpensive. 3) Direct measurement of stress. 4) 1 direction only.	Goodman (1981) Rocha et al (1966)
CSIRO Gauge	Strain gauged borehole insert which is overcored.	1) Complete stress tensor from 1 measurement. 2) Can be used at depth.	C.S.I.R.O. (undated) Jenkins & McKibben (1986) Fama & Peuder (1980)
Serata Stress Meter	Proprietory borehole jack/strain measurement system.	1) Difficult to find comparative testing. 2) Difficult to understand mechanism or equations.	Serata & Kikuchi (1986)

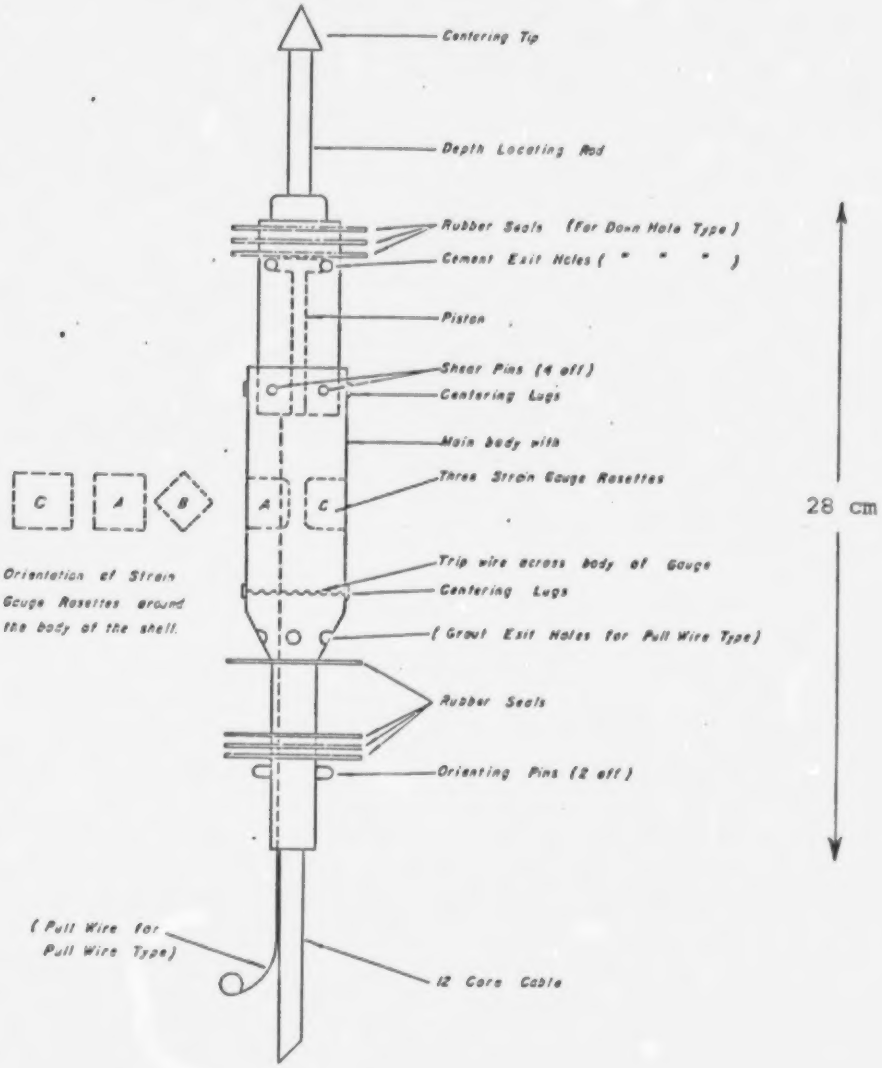
Centering Tip
Depth Locating Rod
Rubber Seals (For Down Hole Type)
Cement Exit Holes (" " ")
Piston
Shear Pins (4 off)
Centering Lugs
Main body with
Three Strain Gauge Rosettes
C
A
B
A
C
Orientation of Strain Gauge Rosettes around the body of the shell.
28 cm
Trip wire across body of Gauge
Centering Lugs
(Grout Exit Holes for Pull Wire Type)
Rubber Seals
Orienting Pins (2 off)
(Pull Wire for Pull Wire Type)
12 Core Cable

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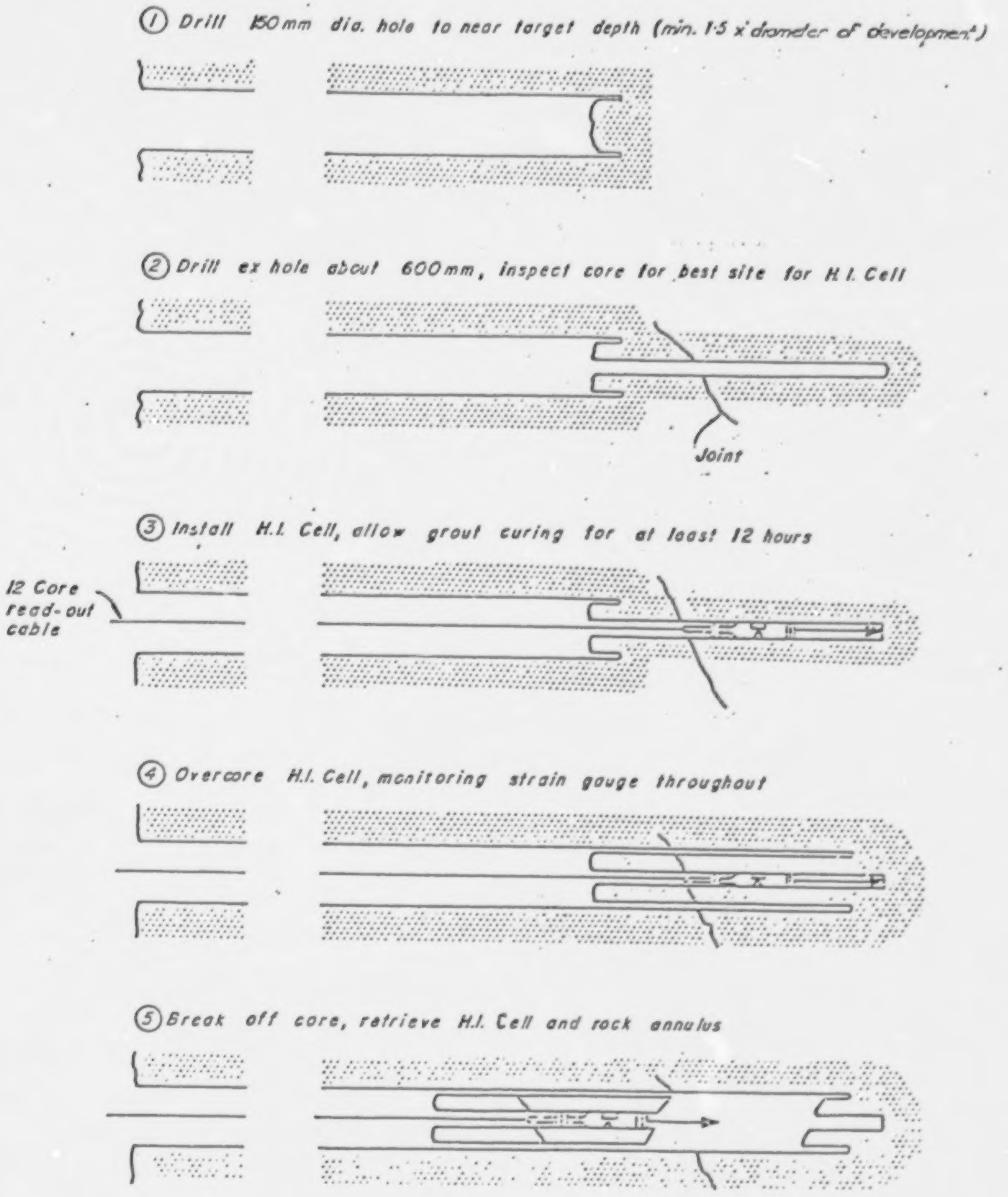
FIGURE 2-6
C.S.I.R.O. HOLLOW INCLUSION STRESS CELL
AFTER C.S.I.R.O. (UNDATED)

SCALE AS SHOWN	DATE SEPT /86	MADE MG	CHKD. GJB	JOB: VG03957	PLATE



① Drill 150mm dia. hole to near target depth (min. 1·5 x diameter of development)

② Drill ex hole about 600mm, inspect core for best site for H.I. Cell

③ Install H.I. Cell, allow grout curing for at least 12 hours

④ Overcore H.I. Cell, monitoring strain gauge throughout

⑤ Break off core, retrieve H.I. Cell and rock annulus

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FIGURE 2-7
FIELD PROCEDURE FOR TEST
MEASUREMENT USING THE C.S.I.R.O.
STRESS CELL (AFTER C.S.I.R.O.)

SCALE N.T.S.	DATE 09/86	MADE M.G.	CHKD. G.J.B.	JOB: V603957	PLATE

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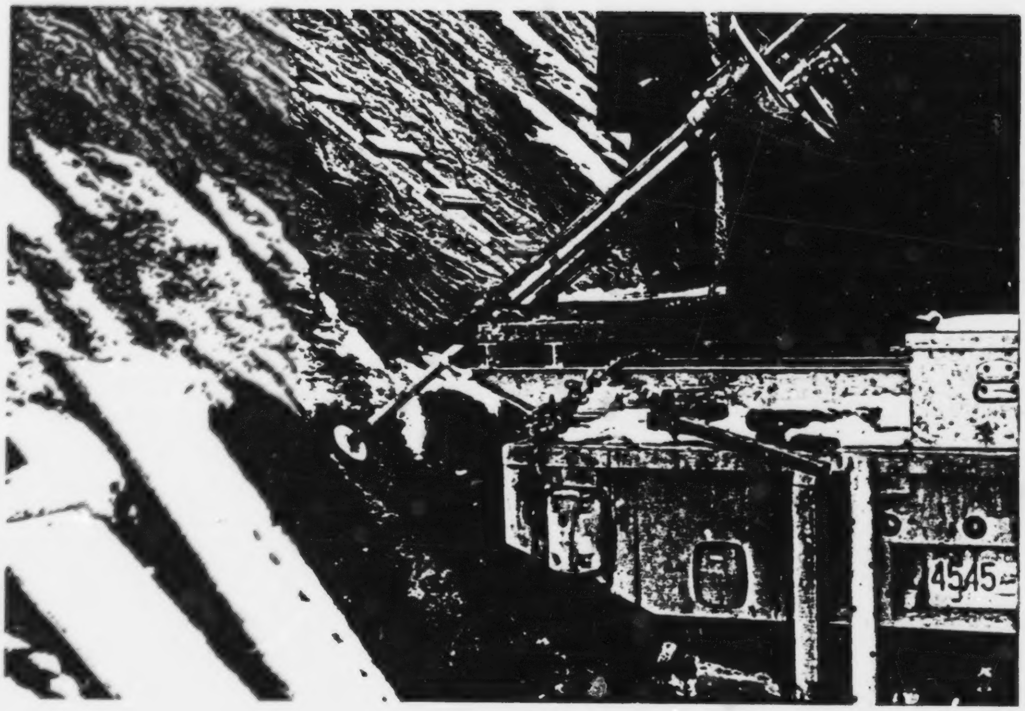


PHOTO 2-2: HI CELL: DRILLING 150 mm DIAM. HOLE

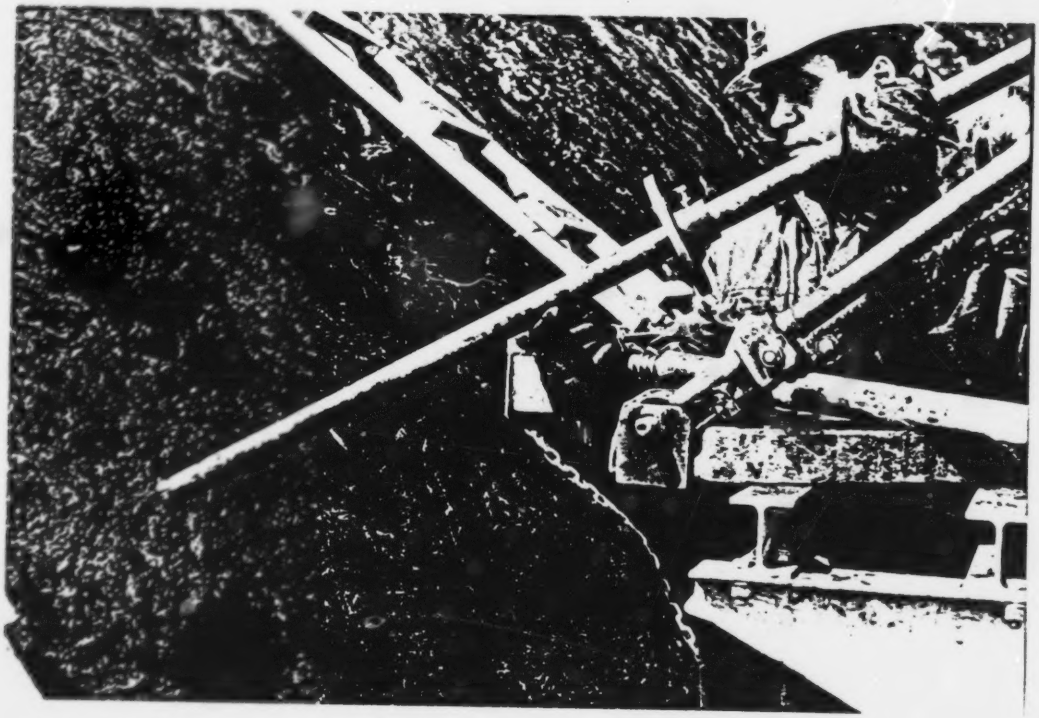


PHOTO 2-3: HI CELL: DRILLING EX HOLE

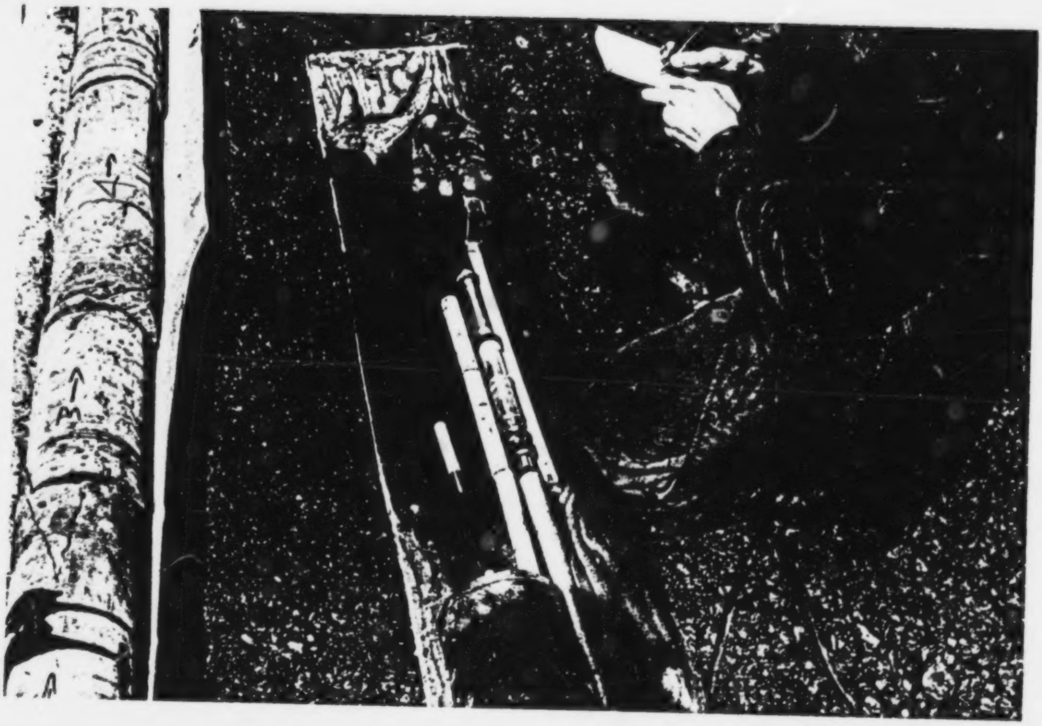


PHOTO 2-4: HI CELL: CHECKING PROPOSED CELL LOCATION WITH EX CORE

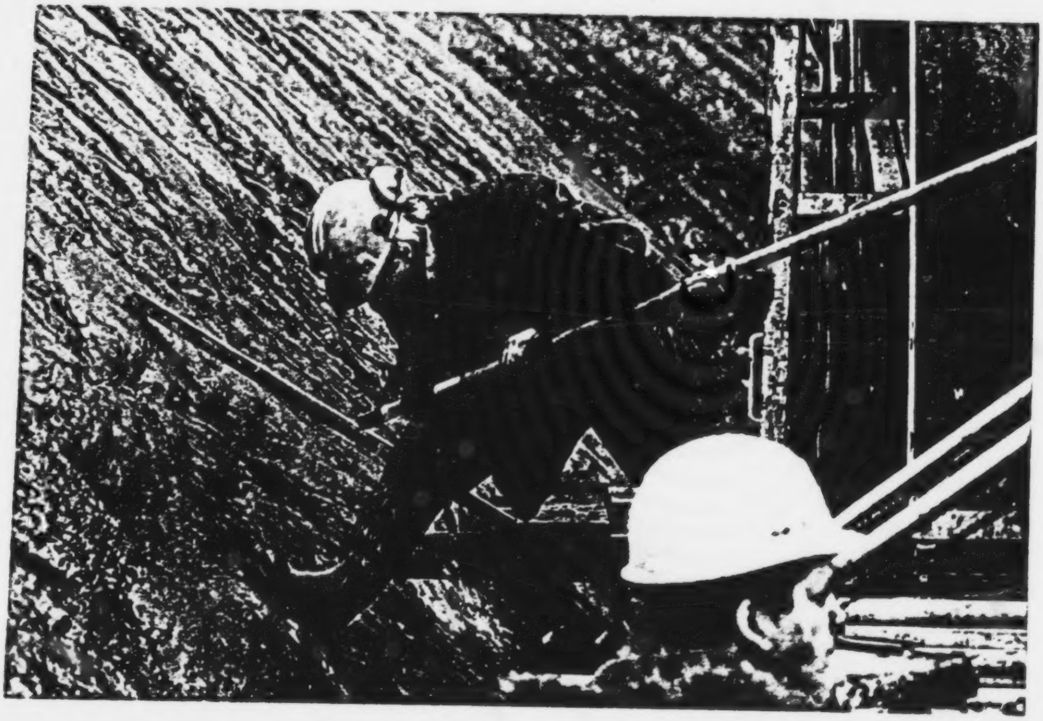


PHOTO 2-5: HI CELL: CLEANING OUT THE EX HOLE

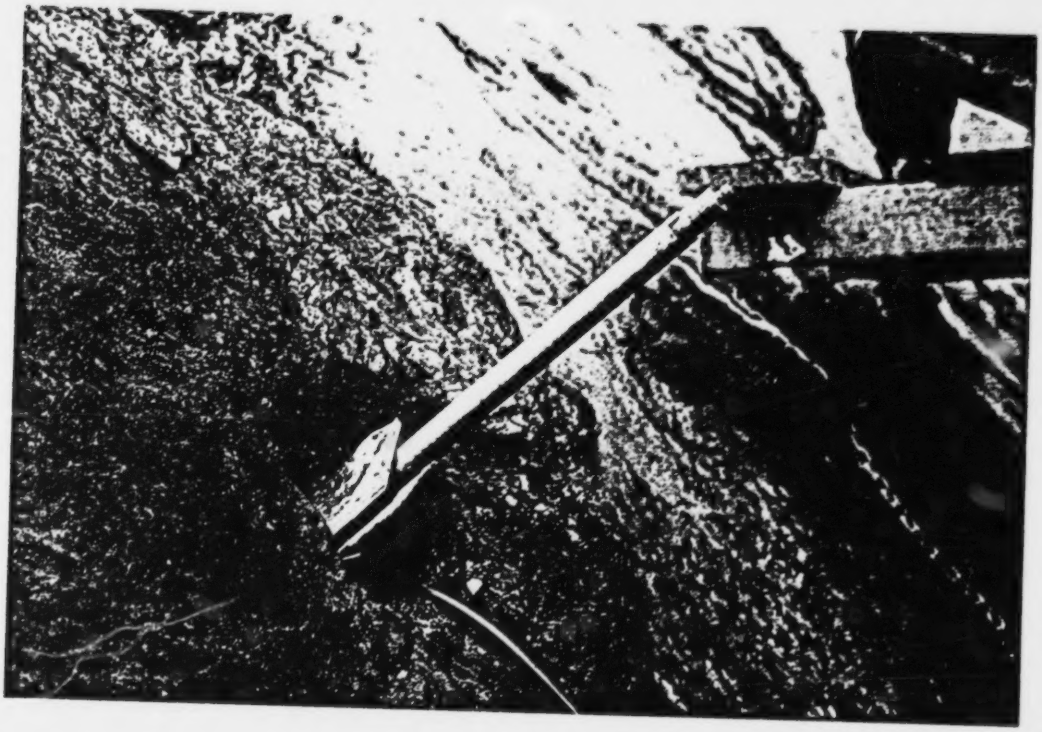


PHOTO 2-6: HI CELL: CELL INSTALLATION

PHOTO 2-7: HI CELL: OVERCORING USING WINKIE DRILL WITH MODIFIED HEAD. NOTE CELL CABLE EXITING FROM HEAD.

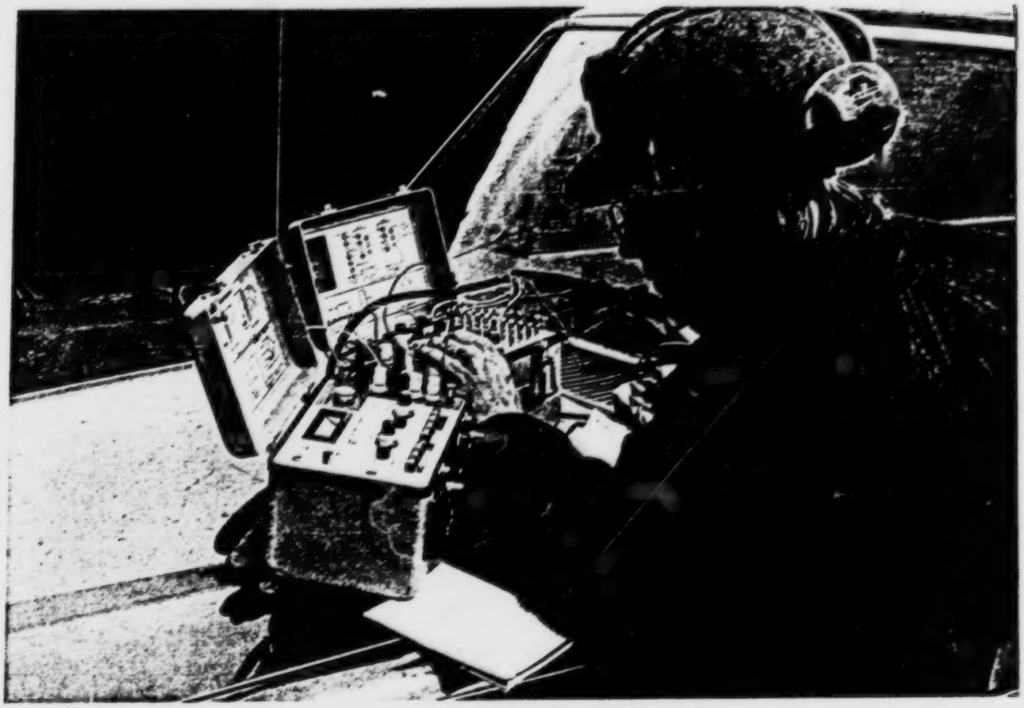


PHOTO 2-8: HI CELL: READINGS BEING TAKEN DURING OVERCORING.

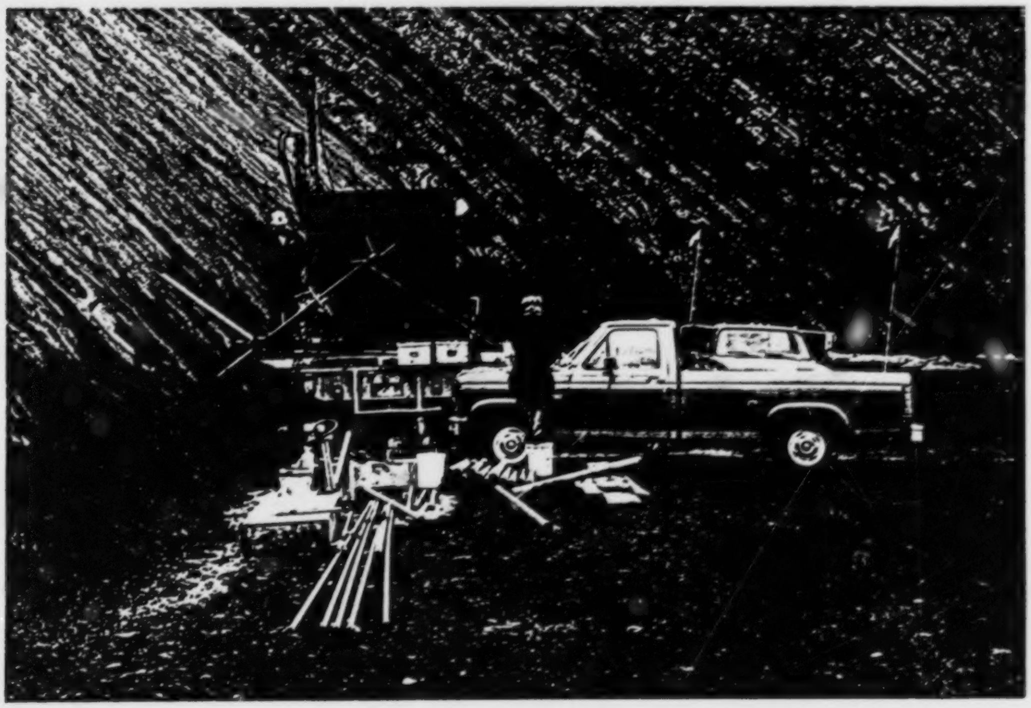


PHOTO 2-9: HI CELL: READING BEING TAKEN FOLLOWING OVERCORING, BUT BEFORE CORE & CELL REMOVAL FROM THE HOLE.

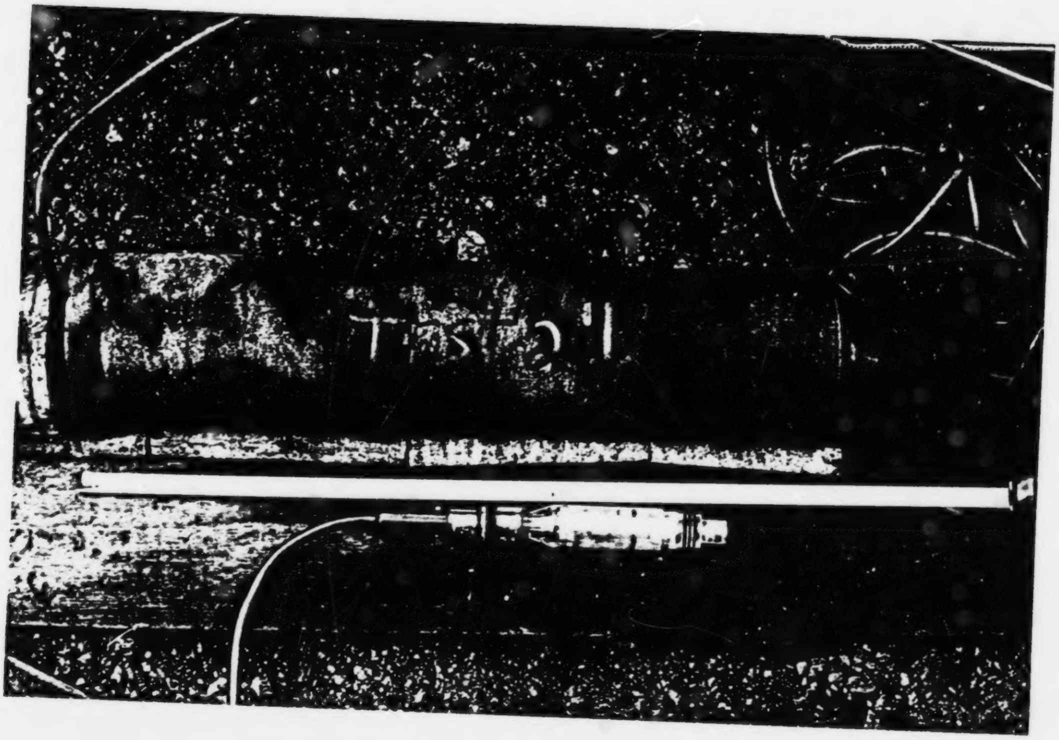


PHOTO 2-10: HI CELL: RECOVERED CELL IN CORE

3.0 MONITORING

3.1 INTRODUCTION

The "observational" technique outlined in Section 1.5 of this report implies a continuous reassessment of footwall conditions during the process of mining. This reassessment should include detailed monitoring of footwall movements or other indications of changes likely to affect stability. Warning of deteriorating stability conditions of a footwall can be obtained by observing a number of parameters:

- changes in geometry;
- footwall movement;
- changes in stress conditions; and
- changes in groundwater conditions.

Monitoring of these parameters should be an important consideration for any open pit mine operation. However, great care is required in interpreting the data collected in any monitoring program. For example, changes in the groundwater pressure may not be critical, stress changes may be of minor importance, and movement may be due to stress relief rather than any impending instability. Hence, all monitoring data should be reviewed carefully by personnel who are experienced not only with monitoring techniques, but also the implications of the results produced by the monitoring.

The following sections describe briefly some techniques which may be considered appropriate for use in open pit mines, and in particular to the monitoring of footwall movements. However, for a more comprehensive review of monitoring techniques, reference should be made to the many excellent texts on this subject (for example, Franklin and Denton (1973)).

3.2 GEOMETRY

During the initial exploration program, prior to onset of mining, detailed drilling should have indicated the various geological features which will form the boundaries of the open pit. In particular, in the case of a footwall, the dip and dip direction of the footwall, and variations over the full extent of the open pit should have been determined. However, as outlined in Section 2.2.1 of this report, drilling accuracy over large distances can be a major problem. Hence, the accurate location of minor geometrical changes in the footwall, such as those outlined in Section 2.2.3, may not be detected at this stage. To ensure that such features are discovered before they become a problem, it is necessary to monitor the footwall below the existing mine floor prior to exposure. In this way, the footwall location on any section can be determined more accurately, and appropriate changes in design of stabilization measures be made prior to the problem being exposed.

One of the most efficient and simplest methods of exploring footwall geometry below the pit floor is by the use of standard mine drilling equipment to drill holes intersecting the footwall. The holes should be accurately surveyed, both to determine collar elevation and borehole orientation. In addition to logging of either rock core (in the case of cored holes) or rock chips (in the case of percussion drilling), holes should be geophysically logged using appropriate geophysical tools to permit the distinction of the coal seams and the footwall. For example, a combination natural gamma log and neutron log would probably suffice. However, the choice of geophysical borehole logging technique depends on anticipated geology and should be reviewed in the light of this knowledge. There are many excellent texts on this topic to which reference should be made (for example, Hoffman, Jordan and Wallace (1982)).

Economic considerations will not normally allow spacing holes close enough together across the pit floor to allow resolution of footwall features smaller than 0.5 to 1.0 m. As a result, we have reviewed the possible use of other geophysical methods for determining changes in geometry including the use of high resolution continuous seismic profiling, seismic refraction, electromagnetic tomography and radar. However, the current "state-of-the-art" of small scale engineering geophysics is such that resolution finer than approximately 0.5 m is difficult to obtain. Hardy Associates (1978) Ltd. is currently in the process of investigating both high resolution continuous seismic and downhole radar techniques for this purpose, and hope to carry out field trials in the near future. Current indications are that these techniques may hold promise.

3.3 MOVEMENT

Movement monitoring provides a direct check on the stability of a footwall. However, experience at Line Creek Mine suggests that small scale movement, as a result of stress relief and closure of fractures as the footwall relaxes, may occur but may not be a precursor to instability. Hence, there is a need to understand the significance of monitored movements and, more importantly, what level, rate or acceleration of movement indicates the onset of instability. Surface monitoring detects changes in footwall topography, whereas borehole monitoring detects differential movement within or below the footwall. Ideally, both surface and borehole monitoring should be undertaken concurrently to give an overall picture of movement.

Conventional survey techniques are both economic and of proven reliability. However, their accuracy still remains a problem, since the movements associated with instability in a footwall can be extremely small. Recent developments in electronic distance measurement (E.D.M.) have greatly improved resolution and modern equipment can measure displacements to an accuracy of better than 10 mm over sight distances of more than 1 km. Measurements are made quickly and the instruments have built-in corrections for variations in temperature and barometric pressure. The targets consist of reflector prisms which can be easily mounted on the footwall slope. One major disadvantage with the surveying technique, is that it is not possible to make readings during heavy rain or snow storms, or when clouds obscure the targets. Thus a backup system of borehole monitoring may be necessary.

Using EDM methods, the complete movement vector should be determined. While the survey techniques outlined above would be applicable for movements in excess of 5 mm, experience at Line Creek suggests that this degree of accuracy is insufficient to detect movements associated with stress relief and crack closure. Hence, movement monitoring using survey techniques can at best be used as a coarse indication.

Other surface methods of measuring footwall movement are the use of surface extensometers and crack gauges. These are usually employed following the development and location of tension cracks at the crest of the footwall. They comprise reference pegs grouted into drillholes on either side of the crack. The distance between the reference pegs is measured to a precision of 0.002 mm using a dial gauge extensometer mounted on an invar rod or bar. Surface extensometers comprising tensioned wires with transducer monitoring are also available. The main disadvantage of this type of instrument is their exposed position, leaving them vulnerable to damage and temperature effects.

Subsurface movement monitoring instruments generally fall into two categories:

1) those that measure extension or compression of the ground in the direction of the drill hole, and

2) those that measure changes in drill hole alignment.

Borehole extensometers usually record differential movements of anchor points installed at various depths from which rods or tension wires extend to a measuring instrument at the borehole collar. It is usual practice to place the deepest anchor below the greatest predicted depth of instability to act as a stable reference point. The quality of instrumentation employed in this field varies considerably. There are devices that are extremely sensitive which is reflected in their price.

At Line Creek, rod extensometers were chosen, and have proven to be quite effective in determining slope movement. Details of these extensometers are given in Appendix 'E', and photographs of one of the extensometers installed at Line Creek are presented in Photographs 3-1 through 3-4. Movements of less than 1 mm have been recorded following mining at the toe of the footwall (see Chapter 6). In addition, the extensometers used at Line Creek were equipped with an electrical readout head (Photographs 3-2 and 3-3), so that readings could be obtained from further down the footwall, following deepening of the mine. This obviated the requirement to access the extensometer heads exposed on the footwall face. There are many manufacturers making such instruments and reference should be made to the various catalogues prior to determining the optimum extensometer type for a particular location. During the course of field work at Line Creek and the subsequent monitoring, it became clear that movements observed in the Line Creek footwall with the inclinometers and extensometers would not have been observed by conventional land survey techniques, even using electronic distance measurement techniques.

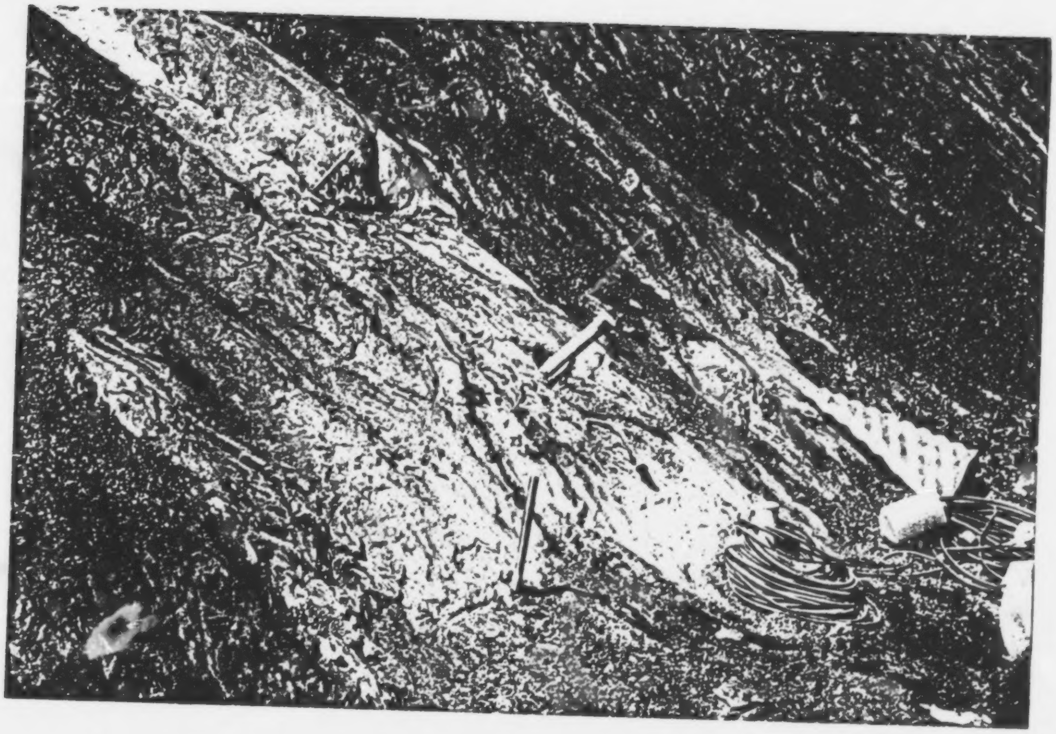


PHOTO 3-1: LINE CREEK EXTENSOMETER - MANUAL HEAD

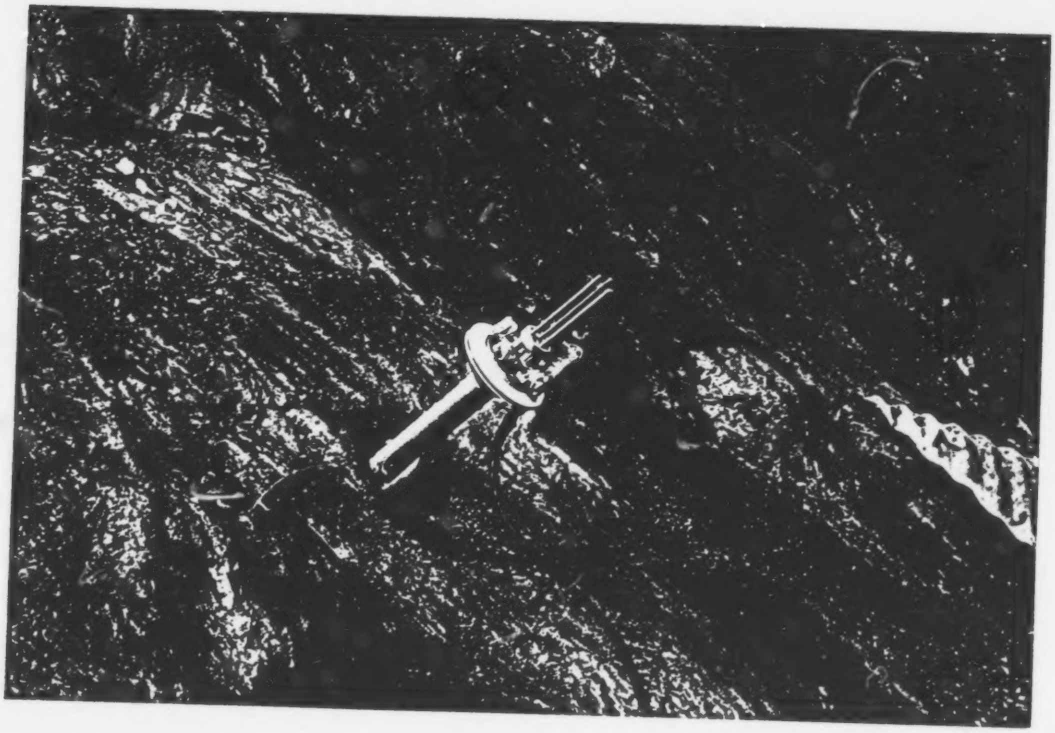


PHOTO 3-2: LINE CREEK EXTENSOMETER - ELECTRICAL HEAD (CAP REMOVED)

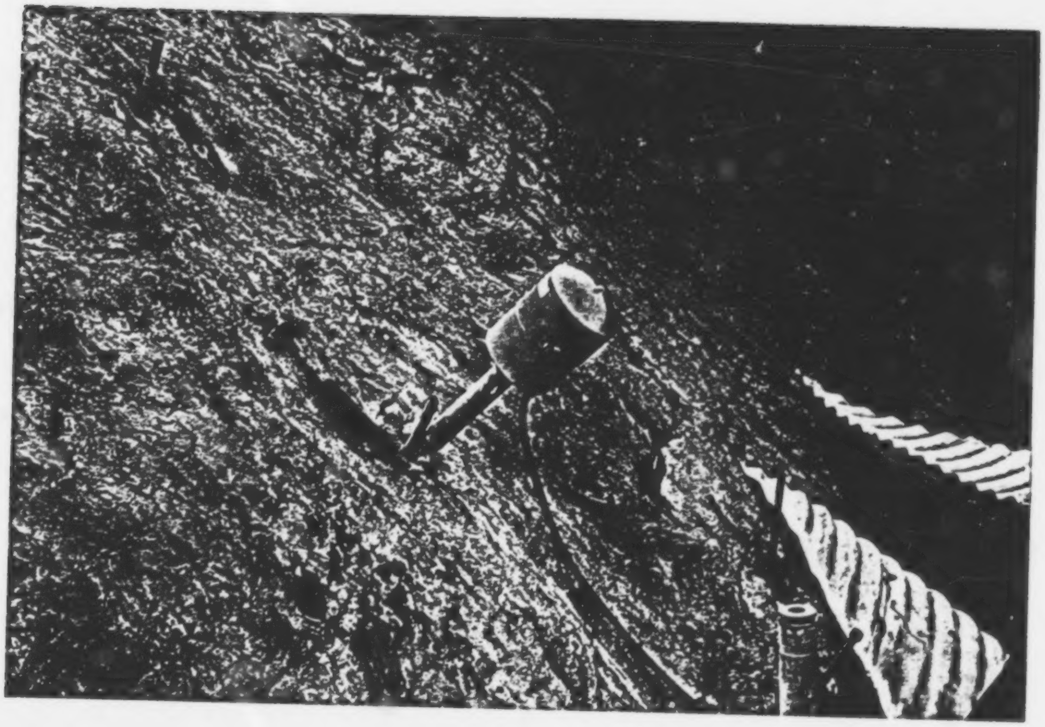


PHOTO 3-3: LINE CREEK EXTENSOMETER - ELECTRICAL HEAD

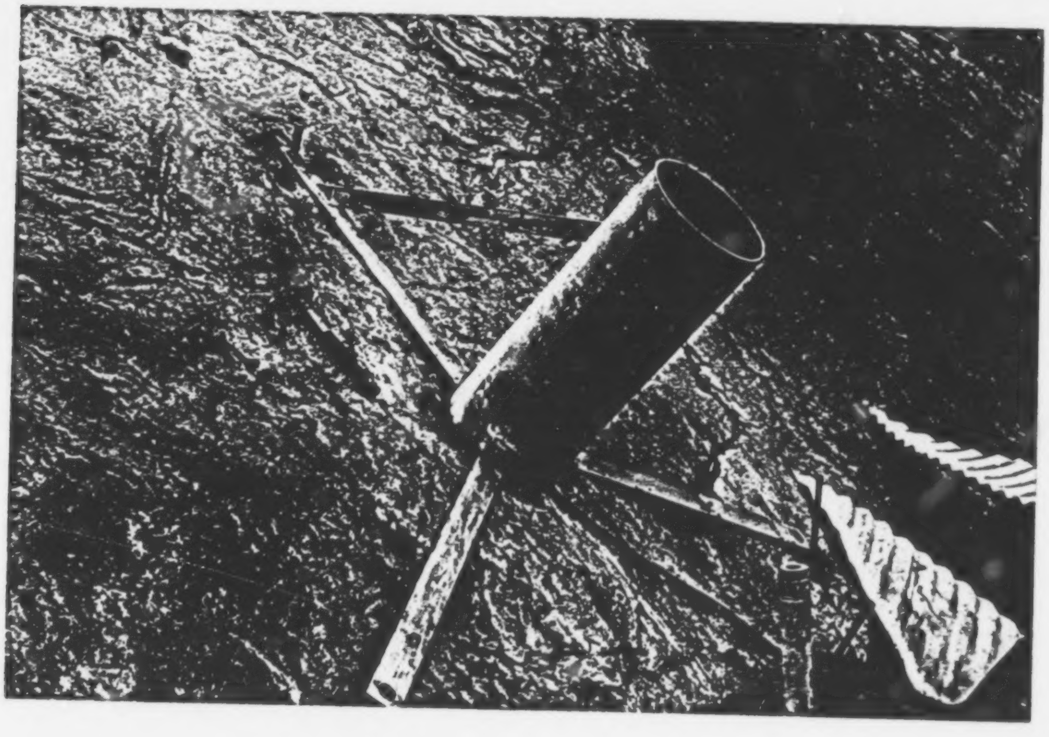


PHOTO 3-4: LINE CREEK EXTENSOMETER - ELECTRICAL HEAD
(WITH ADDED PROTECTION)

Measurements of tilt or inclination in a borehole can be used directly to determine slope movements. Inclinometers have a high sensitivity and can detect differential movements of as small as 0.5 mm per 10 m run of hole. These devices, when installed through a footwall, can indicate downward relaxation of the footwall slab, due to either slope relaxation or impending failure. A good correlation was found between the inclinometers and the extensometers installed at the Line Creek Mine as part of this study (see Chapter 6). Inclinometers for permanent installation usually comprise a chain of pivotted rods. Angular movements between the rods are measured at pivot points using resistance strain gauges mounted on cantilevers.

At Line Creek, a probe inclinometer was used which ran inside inclinometer casing installed in each of the "I" holes. (For instrument details see Appendix 'E'). The probe travels along a special borehole casing or lining tube that incorporates internal guide rails or grooves to align the probe. A drawback with this method is the need to access the collar of the hole for each set of readings. After the subsurface movement patterns for a particular footwall are determined using a grooved casing installation, it may be desirable to install fixed inclinometers at critical locations in the hole, permitting electrical readout at bench level of the movement over a 5 to 10 ft. base length in the hole.

Of the movement monitoring techniques available, experience at Line Creek Mine suggests that the use of rod extensometers and inclinometers is appropriate to detect small scale footwall movement. The resolution of movement detected is only a fraction of a millimetre, an accuracy not possible with conventional survey techniques. Though this resolution is not necessarily indicative of instability, it is important to be able to observe these movements and relate them to stress changes in the footwall and excavation operations at the toe.

3.4 STRESSES

Stress changes can provide an early indication of changing footwall stability conditions resulting from bending or translational movement. In addition, valuable data for analysis may also be obtained.

An indication of stress changes in the footwall can be obtained by observing the loads on rock anchors and rock bolts using load cells. The C.S.I.R.O. hollow inclusion cell, used in this study to determine the state of stress, can also be used to monitor change in stress state. Readout from the pit floor or wall crest is possible.

3.5 GROUNDWATER

Groundwater is probably the most important environmental influence on the stability of footwalls. The use of drainage is both an effective and economic way of dealing with potential instability, and monitoring of water pressures provides useful control on slope conditions. Instability problems can be caused by either excessive water discharge or excessive water pressure. However, it is important to realize that the extent of drainage from a slope is not necessarily indicative of the water pressures contained within it.

If a rock mass is tight, then excessive pressures can exist without large discharges so that a tight rock mass may appear superficially dry, yet may benefit considerably from the drilling of drainage holes. Alternatively, substantial discharges can occur under quite small groundwater pressures. In such cases, the pressures may be no great hazard, but the discharge could lead to progressive erosion and undercutting.

Water pressures are monitored using piezometers, which in their simplest form comprise standpipes installed in a drill hole. However, in rock the use of standpipes is generally not recommended due to the low ground permeability. In low permeability ground, the water takes a considerable time to rise in the tube, and the response to changes in water pressures might be unacceptably slow. Under such conditions, it is necessary to reduce the quantity of water entering the system, in order to detect fluctuations in piezometric pressure. This problem is obviated by the use of pressure transducers which can be read either pneumatically or electrically. These instruments respond to changes of pressure acting on a flexible diaphram while recording diaphram deflections. The design of these instruments is such that only minute quantities of water are required to produce full scale deflection. An additional advantage with this type of piezometer is the fact that it can be read remotely.

It is important to recognize the fact that the majority of flow in rock usually takes place through joints and other types of fissure, rather than through intergranular pore space as it does in soils. Hence, the magnitude of joint permeability exceeds the pore permeability values associated with all but the most porous rock materials. This fact generally results in anisotropic pressure distributions, and artesian and subartesian conditions are frequently encountered. This was found to be the case at Line Creek. It is important that piezometer locations take into account the fractured nature of the ground. The location of piezometers in the borehole should be determined by packer permeability testing (see Section 2.3.1).

4.0 ANALYTICAL DESIGN METHODS

4.1 INTRODUCTION

The appropriate choice of analytical design method is dependent on the particular failure modes being considered. Figure 4-1 shows typical failure modes for footwalls. Possible modes include both translational (involving sliding of footwall strata on cross joints, faults or bedding structures), and buckling (involving outward movement of strata due to convex geometry or groundwater pressures).

Translational failure modes involve sliding of one or more blocks of footwall material along a slip surface daylighting at the toe. The daylighting surface at the toe may consist of bedding (in the case of sedimentary structures or pinchouts), cross faults or cross joints. Plowing translational failure involving movement of the footwall slab beneath material further downslope has not been observed in Western Canada. Walton and Coates (1980) have postulated that plowing action has occurred in some Australian mines. Plowing near the pit floor would tend to be self-arresting; however, plowing high up on the slope could possibly result in serious large-scale movement.

Buckling modes involve the outward movement of part of the slab, as a result of water pressures or geometrical imperfections including rolls or folds, overall large-scale folding or quasi-elastic buckling similar to the buckling of a structural beam under axial loading. Buckling modes of failure are particularly dangerous, as they may result in high velocity movements, and may give little warning prior to failure.

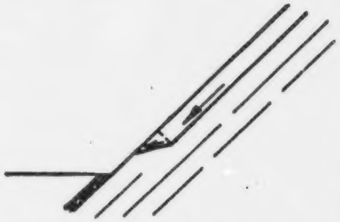
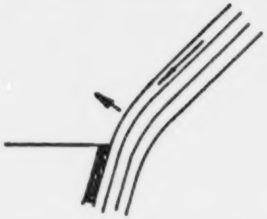
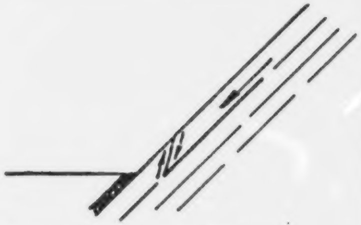
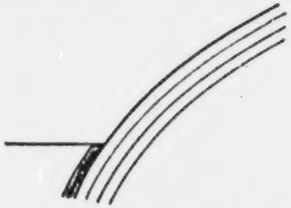
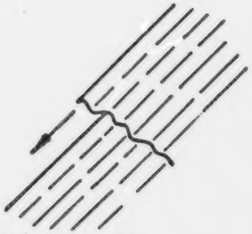
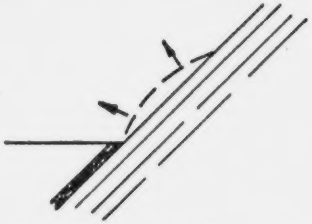
TRANSLATIONAL MODES		BUCKLING MODES	
SCHEMATIC	CAUSES AND FEATURES	SCHEMATIC	CAUSES AND FEATURES
 a) Crosscut at Toe	- Joints dipping into pit excavation - Pinchout of geologic structure (e.g. of sandstone unit) - Blasting damage - Faulting	 a) Buckle on Small Roll	- Roll or fold - Thin bedding - Large dip changes - Low strength
 b) Ploughing at Toe	- Joint or fault with low strength dipping more steeply than bedding	 b) Buckle on Large Scale Fold	- Large scale fold - Thin bedding units - Large dip changes - Low strength
 c) Daylighted Toe	- Cross fault exposing bedding - Depositional feature (e.g. pinchout)	 c) Buckling of Plane Slab	- High slopes - Low bedding strength - High pore pressures

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FIGURE 4-1
SUMMARY OF FOOTWALL
FAILURE MODES AND CAUSES

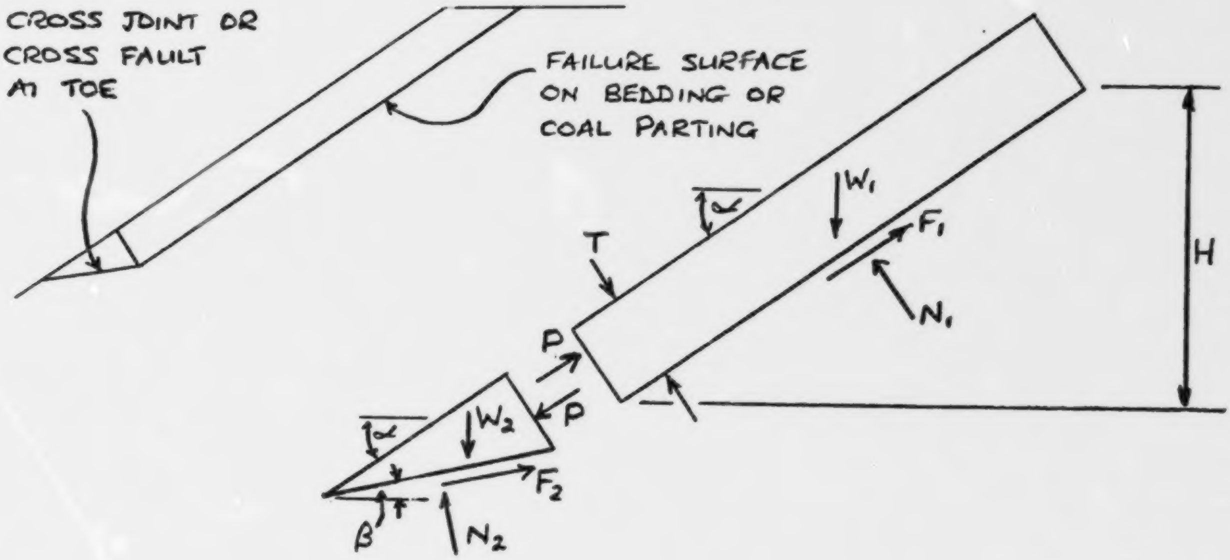
The analysis of translational and buckling failure modes are discussed comprehensively in the following sections, and include newly developed techniques.

4.2 TRANSLATIONAL FAILURE MODES

4.2.1 Cross Joints

The basic two-block cross joint failure mechanism is shown in Figure 4-2. The applicability of this failure mechanism depends on the presence of cross joints dipping out of the slope. Often, these features are relatively rare. For example, the work at Line Creek did not detect any significant cross joints or cross faults. In many cases, bedded footwall deposits tend to develop orthogonal joint systems during folding due to differing elastic modulii of the layers in the bedded deposit. These orthogonal joints are not conducive to translational failure.

Unlike most of the other failure mechanisms and modes which can occur on footwalls, cross joint translational failure has been discussed at some length in the literature. For example, Brawner et al (1971) discuss the application of this failure mechanism to footwalls in the Kootenays near Sparwood, B.C. Many of the footwalls in Western Canada have been analyzed and/or designed on the basis of this failure mechanism, and Stimpson and Robinson (1982) have presented a Fortran computer program to analyze it.


CROSS JOINT OR CROSS FAULT AT TOE
FAILURE SURFACE ON BEDDING OR COAL PARTING
W_1
F_1
N_1
α
T
H
P
P
W_2
α
F_2
β
N_2

ASSUMPTIONS : TWO BLOCK FAILURE MECHANISM, AS SHOWN ABOVE
DRY, COHESIONLESS CONDITIONS
ϕ = ANGLE OF SHEARING RESISTANCE
γ = UNIT WEIGHT
F = FACTOR OF SAFETY
NEGLIGIBLE INTER-BLOCK SHEAR FORCES

FOR UPPER BLOCK: $W_1 = \dfrac{TH\gamma}{\sin\alpha}$ AND $F_1 = N_1 \dfrac{\tan\phi}{F}$

RESOLVING PERP. BEDDING: $N_1 = W_1 \cos\alpha$

RESOLVING PARALLEL BEDDING: $P = W_1 \sin\alpha - F_1$

$$\therefore P = TH\gamma\left(1 - \frac{\tan\phi}{F\tan\alpha}\right) \quad \text{———} (1)$$

FOR LOWER BLOCK: $W_2 = \dfrac{T^2\gamma}{2\tan(\alpha-\beta)}$ AND $F_2 = N_2 \dfrac{\tan\phi}{F}$

RESOLVING PERP. CROSSJOINT: $N_2 = W_2\cos\beta + P\sin(\alpha-\beta)$

RESOLVING PARALLEL CRSJNT: $F_2 = W_2\sin\beta + P\cos(\alpha-\beta)$

$$\therefore P = \frac{T^2\gamma(\cos\beta\tan\phi - F\sin\beta)}{2\sin(\alpha-\beta)\left[F - \tan(\alpha-\beta)\tan\phi\right]} \quad \text{———} (2)$$

PUTTING EQUATION (1) EQUAL TO EQUATION (2), AND SOLVING FOR F RESULTS IN A QUADRATIC EQUATION OF THE FORM

$$AF^2 + BF + C = 0.$$

SOLVING FOR H RESULTS IN THE FOLLOWING EXPRESSION:

$$H = \frac{T(\cos\beta\tan\phi - F\sin\beta)(1 - \tan\phi / F\tan\alpha)^{-1}}{2\sin(\alpha-\beta)\left[F - \tan(\alpha-\beta)\tan\phi\right]} \quad \text{———} (3)$$

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FIGURE 4-2
TRANSLATIONAL STABILITY WITH
CROSS JOINT

SCALE NTS	DATE 10/86	MADE GJB	CHKD. M.G.	JOB: VG03957	PLATE -

This failure mechanism occurs on bedding pinchouts in which a stratum of sandstone, for example, pinches out due to depositional variations. On some footwalls, pinchouts may be accompanied by an underlying coaly parting, resulting in low strength conditions on the daylighted bedding. Discontinuity orientations of the bedding pinchout features are similar to those of cross jointed or cross faulted features, and may be analyzed using the same method.

As a general "rule of thumb", a cross joint feature would create instability under the follwing dry, cohesionless conditions:

$$(\alpha - \beta) < (90 - \phi) \qquad (3\text{-}1)$$

where: α = slope angle, greater than angle of shearing resistance along bedding (may be different to angle of shearing resistance for cross joints).

β = dip of cross joint feature.

ϕ = angle of shearing resistance along the cross joint.

It should be noted that the stability of the slope could be greatly affected by the presence of groundwater and a cohesion component to shear strength.

The above simplified rule neglects any shear stress acting between the rectangular block above and the triangular block at the toe. This is reasonable for thin slabs since, if any shear stress develops, the slabs will tend to lift. As the slabs become thicker, the analysis becomes more conservative due to the presence of this shearing resistance. For long thin slabs, as normally occur in footwalls, the assumption of negligible shearing resistance between the blocks is considered reasonable.

In addition, this simplified rule does not consider cohesion which may act along the cross joint surface in the form of infilling material or rock bridges. In some cases, relatively small amounts of cohesion acting along this cross joint surface could provide stability. This cohesion may be particularly significant if intact rock bridges have to be broken to shear the cross joint surface.

An example of the anlysis outlined above, assuming the failure mechanism outlined in Figure 4-2, is presented in Figure 4-3a. This example indicates the background to the potential generation of stability charts, examples of which are shown in Figure 4-3b. A full set of charts similar to those in Figure 4-3b could be produced for a range of values of slope angle ( ), slab thickness (T), and angle of shearing resistance (ϕ). Each chart would show a series of curves, one for each value of cross joint angle ( ), showing the relationship between slope height (H) and factor of saftey (F).

4.2.2 Plowing Failure

The general mechanism of plowing failure is shown on Figure 4-1. As far as the authors are aware, this failure mechanism has not been observed in Western Canada; however, it has been postulated for failures in Australia by Walton and Coates (1980).

One of several methods of analysis is outlined in Figure 4-4a. This method assumes failure to be by sliding of a lower block out of the face, rather than, for example, rotation. It also assumes the presence of a release surface (joint) orthogonal to bedding and parallel to the footwall. While the first assumption (stated above) is realistic, the second is conservative, particularly for very thick slabs.

GIVEN PARAMETERS:

ANGLE OF SHEARING RESISTANCE, ϕ 30°

SLOPE ANGLE, α 40°

SLAB THICKNESS, T 2 m.

VARIABLE PARAMETERS:

CROSS JOINT ANGLE, β −10° TO +20°

FACTOR OF SAFETY, F 0.90 TO 2.00

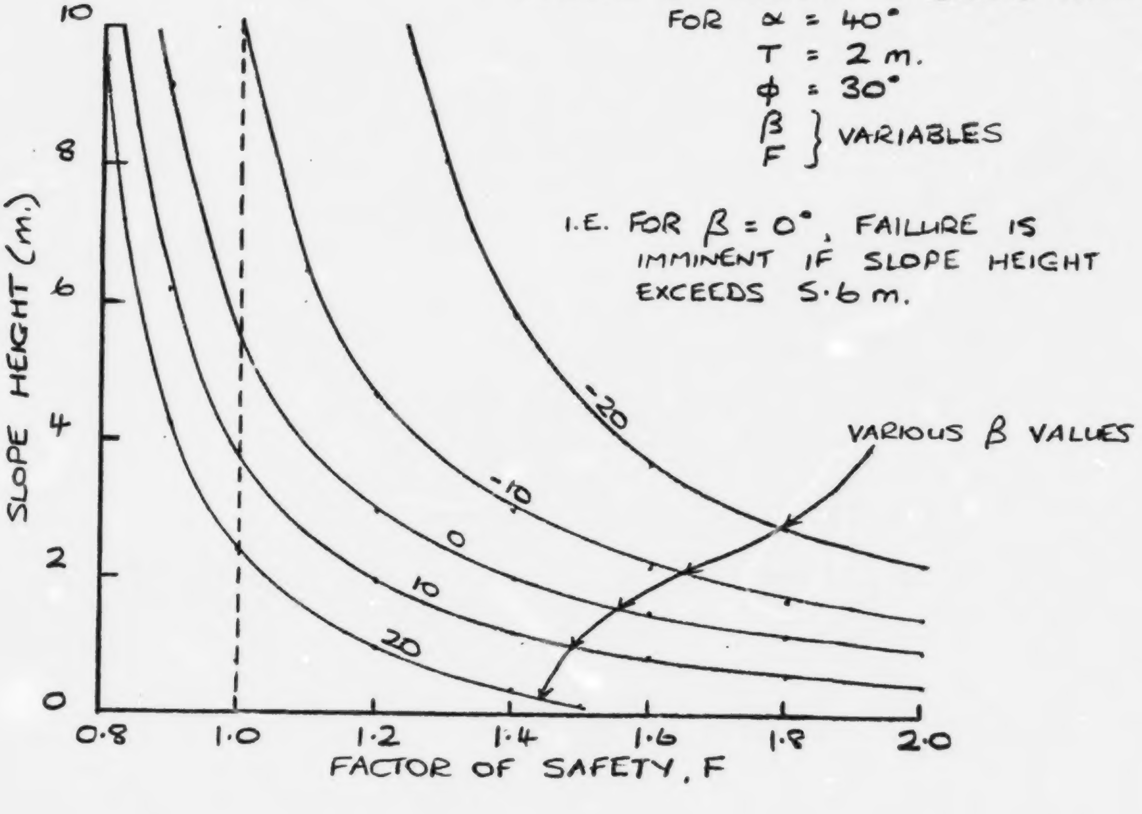
PARAMETER TO BE DETERMINED:

SLOPE HEIGHT, H

$$H = \frac{T(\cos\beta\tan\phi - F\sin\beta)(1-\tan\phi/F\tan\alpha)^{-1}}{2\sin(\alpha-\beta)[F-\tan(\alpha-\beta)\tan\phi]} \qquad (3)$$

(FIG. 4-2)

SOLVING ABOVE EQUATION FOR H FOR VARIABLE INPUT PARAMETERS RESULTS IN GRAPHICAL RESULTS AS SHOWN.



FACTOR OF SAFETY V. SLOPE HEIGHT
FOR $\alpha = 40°$
$T = 2$ m.
$\phi = 30°$
β, F } VARIABLES

I.E. FOR $\beta = 0°$, FAILURE IS IMMINENT IF SLOPE HEIGHT EXCEEDS 5.6 m.

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FIGURE 4-3a
EXAMPLE OF CROSS JOINT ANALYSIS

SCALE NTS	DATE 10/86	MADE GJB	CHKD. MG	JOB: VG03957	PLATE –

SLOPE ANGLE, $\alpha = 40°$
SLAB THICKNESS, T=9m

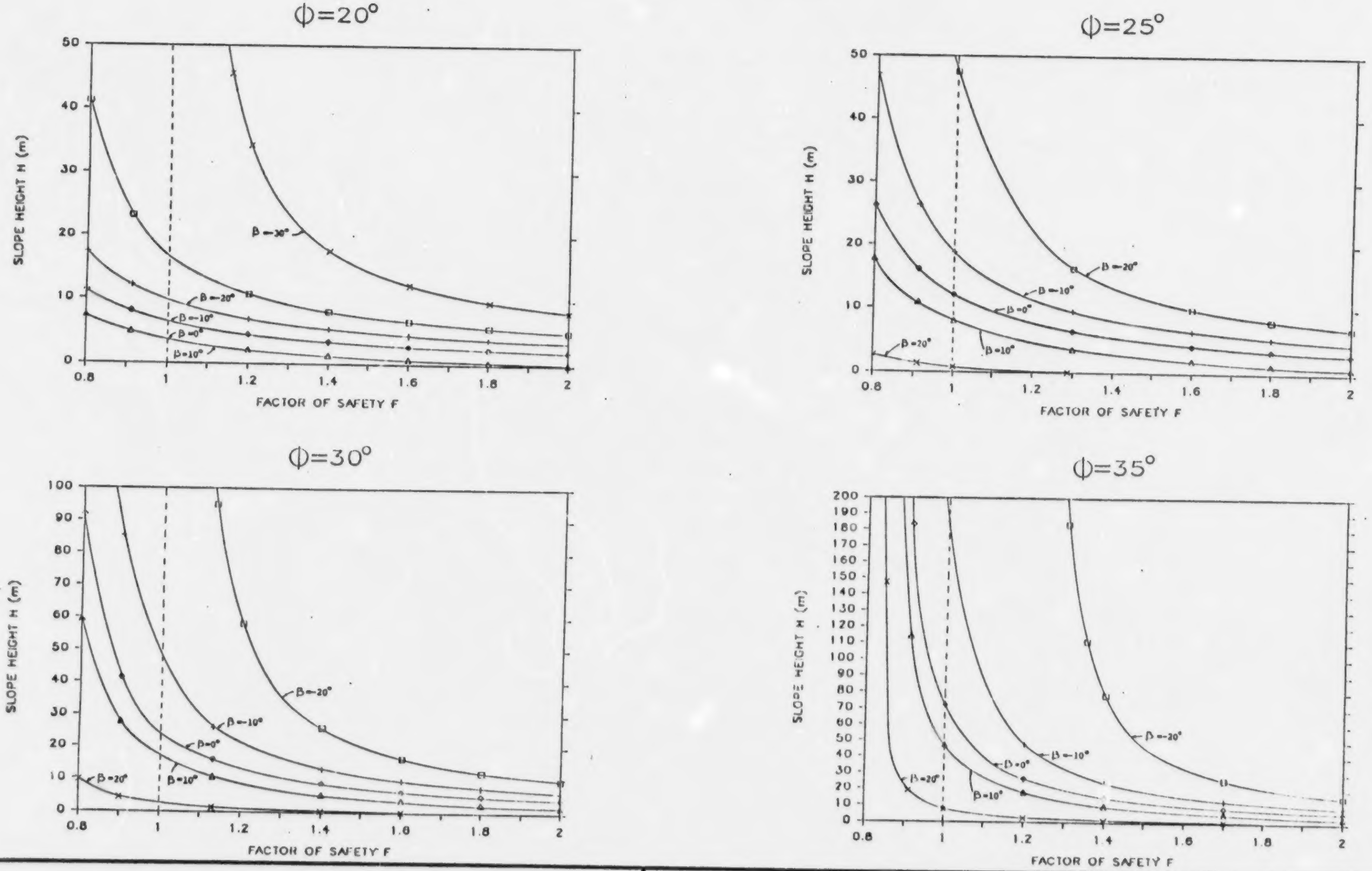

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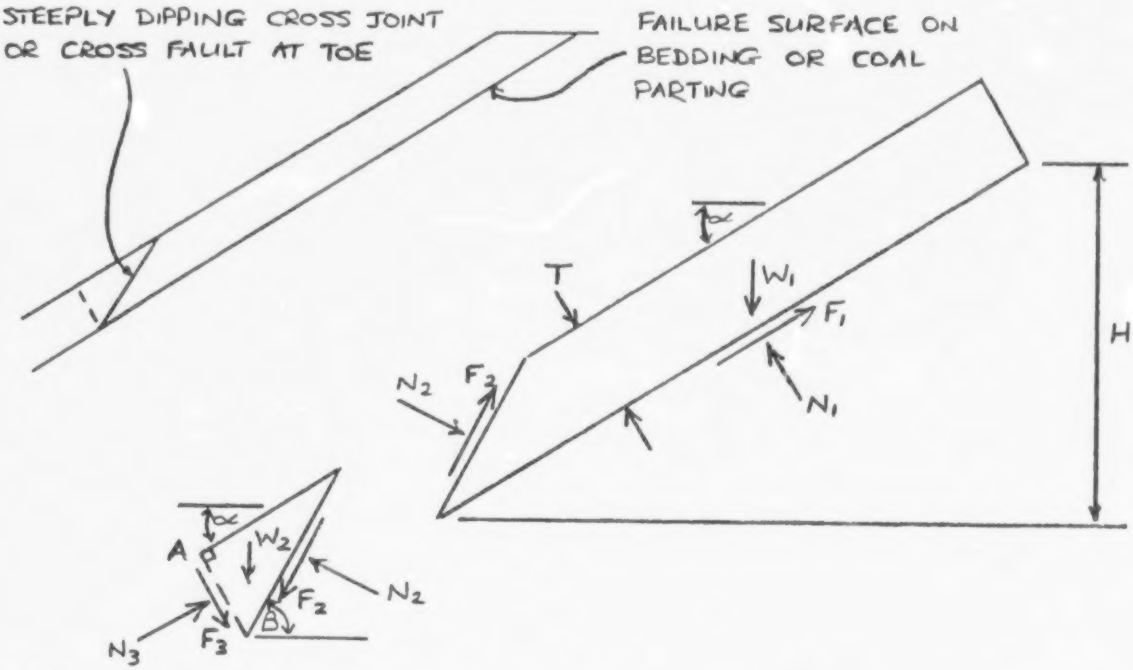
FIGURE 4-3b
EXAMPLE OF CROSS-JOINT ANALYSIS
STABILITY CHARTS


STEEPLY DIPPING CROSS JOINT OR CROSS FAULT AT TOE
FAILURE SURFACE ON BEDDING OR COAL PARTING
α
T
W_1
F_1
N_2
F_2
N_1
H
α
A
W_2
F_2
N_2
β
N_3
F_3

ASSUMPTIONS : TWO BLOCK, TWO DIMENSIONAL FAILURE MECHANISM
DRY, COHESIONLESS CONDITIONS
LOWER BLOCK FAILS BY SLIDING OUT OF FACE
(ALTERNATIVE MECHANISM – ROTATION ABOUT POINT A)
ϕ = ANGLE OF SHEARING RESISTANCE
γ = UNIT WEIGHT
F = FACTOR OF SAFETY

FOR UPPER BLOCK : $W_1 = T\gamma\left(\frac{H}{\sin\alpha} - \frac{T}{2\tan(\beta-\alpha)}\right)$

$F_1 = N_1\frac{\tan\phi}{F}$ $\quad$ $F_2 = N_2\frac{\tan\phi}{F}$

RESOLVING PERP. BEDDING: $N_1 = W_1\cos\alpha + N_2\cos(\beta-\alpha) - F_2\sin(\beta-\alpha)$ (1)

RESOLVING PARL. BEDDING: $F_1 + F_2\cos(\beta-\alpha) + N_2\sin(\beta-\alpha) = W_1\sin\alpha$ (2)

FOR LOWER BLOCK: $W_2 = \frac{T^2\gamma}{2\tan(\beta-\alpha)}$ $\quad$ $F_3 = N_3\frac{\tan\phi}{F}$

RESOLVING PERP. JOINT: $N_2 = W_2\cos\beta + F_3\cos(\beta-\alpha) + N_3\sin(\beta-\alpha)$ —(3)

RESOLVING PARL. JOINT: $F_2 + W_2\sin\beta + F_3\sin(\beta-\alpha) = N_3\cos(\beta-\alpha)$ —(4)

SOLVING ABOVE EQUATIONS FOR F RESULTS IN A CUBIC EQUATION OF THE FORM

$$AF^3 + BF^2 + CF + D = 0$$

THEREFORE, IT IS RECOMMENDED THAT THE ABOVE EQUATIONS BE SOLVED FOR H, FOR A GIVEN (REQUIRED) FACTOR OF SAFETY (F).

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FIGURE 4-4a
DERIVATION OF EQUATIONS FOR
PLOWING STABILITY

SCALE NTS DATE 10/86 MADE GJB CHKD. MG JOB: VG03957 PLATE –

As a general "rule of thumb", the following relationship would indicate potential instability under dry, cohesionless conditions:

$$(\beta - \alpha) < (90 - \phi) \qquad (3\text{-}3)$$

where: β = dip of cross joints (dipping more steeply than bedding)
α = dip of bedding
ϕ = angle of shearing resistance of cross joints.

Notwithstanding the conservative assumptions made in arriving at the above rule, if equation (3-3) is fulfilled the slab will behave "rigidly" and all axial forces within the slab above the block will be transmitted through the lower block into the slab below.

It should also be noted that where steeply dipping cross joints occur close to the pit floor, this mechanism of failure is unlikely, due to the large mass of material on the pit floor that would have to be displaced. However, the mechanism is possible higher up on the slope and, at that location, could result in large volume displacements.

Using the equations derived in Figure 4-4a on a trial example (Figure 4-4b), it is possible to determine the relationship between slope height and factor of safety for a given set of remaining slope parameters. This example, using fairly typical data, indicates that a large driving force is required to precipitate plowing failure. In view of this observation, and the fact that in Western Canada cross joints dipping more steeply than bedding have, in the past, been relatively rare, design charts have not been

GIVEN PARAMETERS:

ANGLE OF SHEARING RESISTANCE, ϕ = 30°
SLOPE ANGLE, α = 40°
CROSS JOINT ANGLE, β = 60°
SLAB THICKNESS, T = 2 m.
UNIT WEIGHT, γ = 25 kN/m.^{3}

VARIABLE PARAMETER:

FACTOR OF SAFETY, F = 1·00 TO 2·00

PARAMETER TO BE DETERMINED:

SLOPE HEIGHT, H

$$W_1 = 2 \times 25 \times \left(\frac{H}{\sin 40^\circ} - \frac{2}{2\tan(60-40)^\circ} \right) = (77{\cdot}79H - 137{\cdot}37)$$

$$W_2 = 137{\cdot}37$$

$$F_1 = \frac{0{\cdot}58N_1}{F}, \quad F_2 = \frac{0{\cdot}58N_2}{F}, \quad F_3 = \frac{0{\cdot}58N_3}{F}$$

FROM EQUATIONS (1) THROUGH (4) IN FIGURE 4-4(a):

$$N_1 = (77{\cdot}79H - 137{\cdot}37)\cos 40 + N_2\cos 20 - \frac{0{\cdot}58N_2}{F}\sin 20$$

$$\frac{0{\cdot}58N_1}{F} + \frac{0{\cdot}58N_2}{F}\cos 20 + N_2\sin 20 = (77{\cdot}79H - 137{\cdot}37)\sin 40$$

$$N_2 = 137{\cdot}37\cos 60 + \frac{0{\cdot}58N_3\cos 20}{F} + N_3\sin 20$$

$$\frac{0{\cdot}58N_2}{F} + 137{\cdot}37\sin 60 + \frac{0{\cdot}58N_3}{F}\sin 20 = N_3\cos 20$$

SOLVING ABOVE EQUATIONS FOR H BY SPECIFYING VARIABLE VALUES FOR F GIVES GRAPHICAL RESULTS AS SHOWN.

CONCLUSION: GIVEN ABOVE PARAMETERS AND ASSUMPTIONS IN FIGURE 4-4(a), PLOWING FAILURE COULD OCCUR IF SLOPE HEIGHT EXCEEDS 60 m.

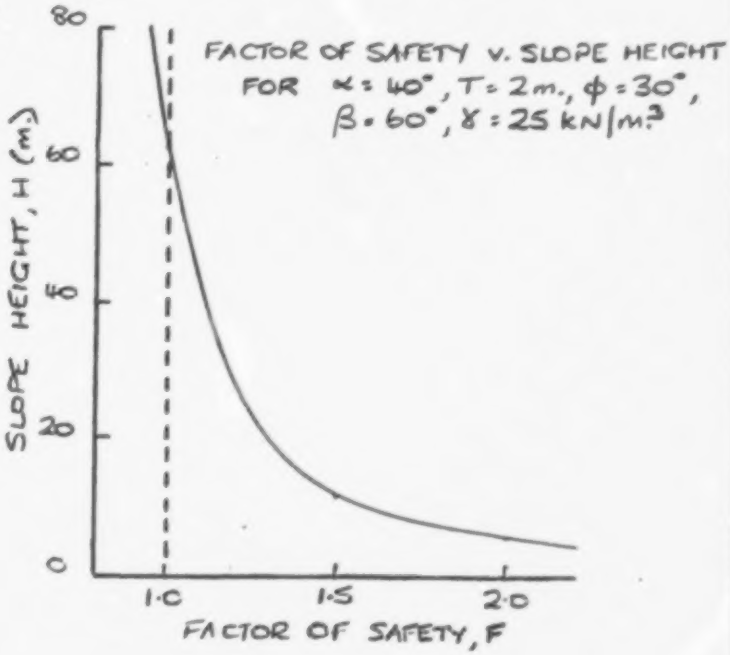

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FIGURE 4-4b
EXAMPLE OF PLOWING ANALYSIS

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generated. Nevertheless, the mechanism could occur in some sedimentary bedding depositional features, or along thrust faults.

4.2.3 Daylighted Bedding

Of the various structures that could cause failure, daylighted bedding may be the most common. Bedding may be daylighted by cross faults, bedding pinchouts or sedimentary structures as exemplified in Figure 4-1. Photographs 4-1 and 4-2 show daylighted bedding due to sedimentary features and cross faulting on pit walls.

Perhaps the main non-depositional reason for daylighted bedding is faulting of the coal seam along surfaces perpendicular to bedding.

If bedding planes on the footwall are daylighted and if the bedding dip exceeds the angle of shearing resistance, failure of slabs on the footwall should be expected. The kinematic condition for failure of dry, cohesionless slopes where negligible rock bridges or other cohesion-producing elements exist is:

$$\alpha > \phi \qquad (3\text{-}4)$$

where: α = dip of bedding
ϕ = angle of shearing resistance.

For typical ranges of ϕ along bedding in the order of 25 to 40°, it is apparent that this mechanism may be a problem for many of the coal mine footwalls in Western Canada.

PHOTO 4-1: DAYLIGHTED BEDDING - EXAMPLE 1

PHOTO 4-2: DAYLIGHTED BEDDING - EXAMPLE 2

The frequency of failure for this type of mechanism varies among different coal mines in Western Canada, depending upon the bedding structures present. Where the foregoing kinematic test indicates the failure to be likely, the only alternatives are removal of the problem material or anchoring. These alternatives will be discussed further in Chapter 5. Through better understanding of the depositional environment which has created such problem features, it may be possible to improve predictions of where they might occur.

Plane failure design charts, which can be used for cases of daylighted bedding, have been developed by Hoek & Bray (1981). Therefore, additional charts have not been developed for this failure mechanism.

4.3 BUCKLING FAILURE MODES

4.3.1 Plane Slabs

While large-scale, plane buckling failures of thick-slabbed slopes and footwalls have not been documented, plane buckling failures in thin mudstone strata are relatively common.

Small plane buckles typically have an en echelon "house-of-cards" structure, as suggested by Figure 4-5 and Photograph 4-3. This structure has also been observed in larger scale pit floor buckles (for example, Adams (1982)). Similar features may form on large open pit slopes. However, no failures due to this mechanism have presently been recognized in Western Canada.

Walton and Coates (1980) and Cavers (1981) have applied Euler's classic theory of buckling to this failure mode. There is a

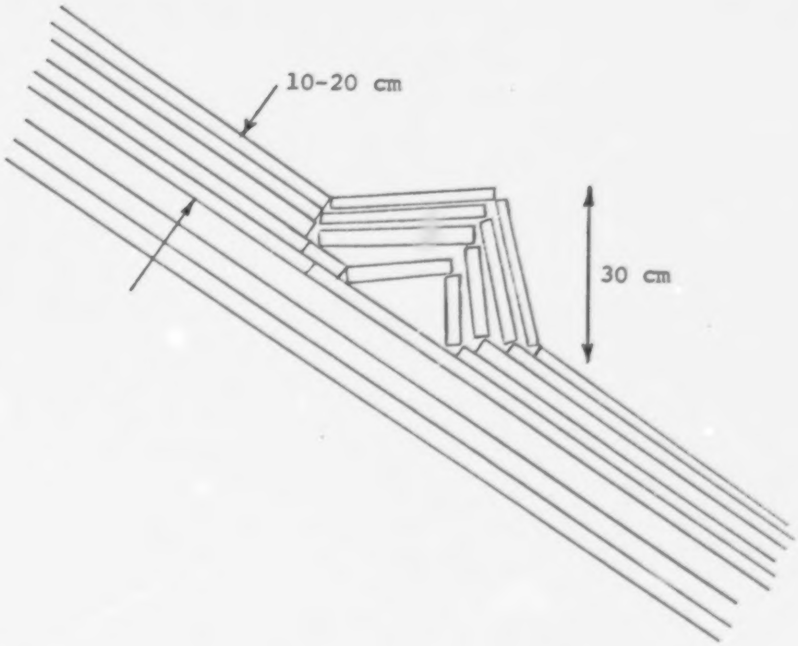

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FIGURE 4-5
TYPICAL "HOUSE OF CARDS"
STRUCTURE OBSERVED IN LAMINATED
MUDSTONES ON FOOTWALLS

SCALE AS SHOWN	DATE 09/86	MADE M.G.	CHKD. G.J.B.	JOB: VG03957	PLATE

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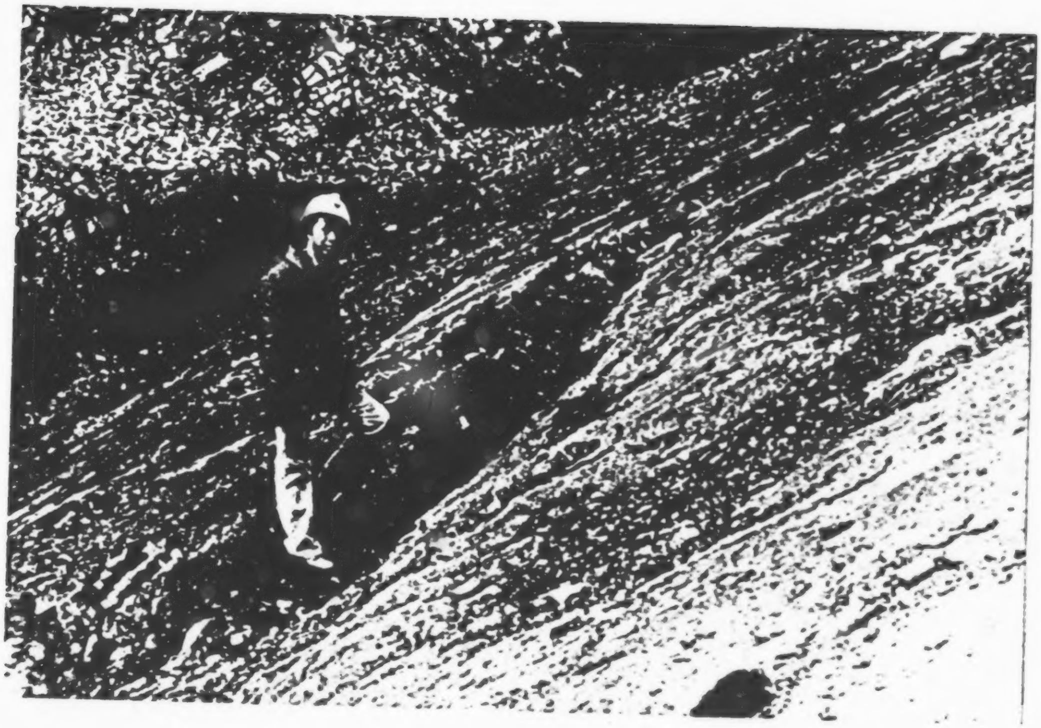
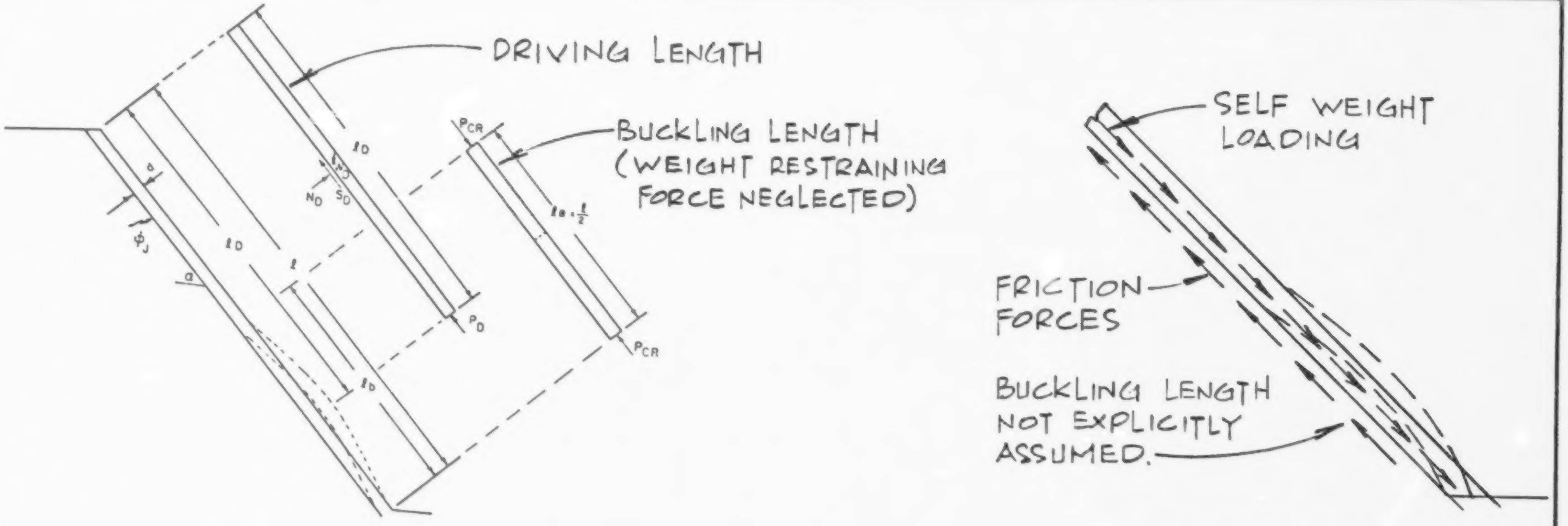


PHOTO 4-3: "HOUSE-OF-CARDS" BUCKLING FAILURE

problem in applying this classic theory to the buckling of open pit rock strata, since it involves the concept of the loading of a weightless column by an end force. This is discussed in Cavers (1981) in which an assumption is made about the proportion of the slab length which would buckle. Gravitational driving forces (due to the inclination of the slab) are neglected within the lower half of the buckling area, as is the self weight of the buckling slab. These assumptions were based on model testing, but it was not possible to calibrate the model to actual large scale pit failures. Thus, considerable uncertainty existed as the whether the model is conservative or not, and also uncertainty existed with respect to the determination of an appropriate factor of safety. Nevertheless, this buckling model has been used fairly extensively in Western Canada by a number of consulting engineering firms to design open pit mine slopes.

In the present study, a slightly different model based on Timoshenko and Goodier (1951) has been used, which allows the imposition of a distributed driving force along the rock strata due to the gravitational loading on the buckling stratum. However, the component of the gravitational force perpendicular to the slab which tends to resist the buckling movement is still neglected, as are the moment forces developed on the slab ends, the tensile strength of the material to support a buckled shape and displacements tending towards bucking shapes. The additional assumption used in the present analysis is that the slab ends are pinned. Thus, it is considered that the analytical results presented herein are somewhat conservative and, on this basis, a factor of safety of the order of 1.5 is considered reasonable. A comparison of the Cavers (1981) model and the existing model is presented in Figure 4-6, and the


DRIVING LENGTH
BUCKLING LENGTH (WEIGHT RESTRAINING FORCE NEGLECTED)
P_{CR}
P_D
P_{CR}
ℓ_D
N_D
S_D
ℓ_D
ℓ
ℓ_D
$\ell_B = \frac{\ell}{2}$
α
ϕ_j
SELF WEIGHT LOADING
FRICTION FORCES
BUCKLING LENGTH NOT EXPLICITLY ASSUMED.

A) CAVERS (1981) PLANE BUCKLING MODEL. THE ASSUMPTIONS IN THIS MODEL GIVE A SLAB LENGTH 40% LONGER THAN FOR MODEL IN (B).

B) MODEL USED IN THIS REPORT.

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FIGURE 4-6
COMPARISON OF OLDER AND PRESENT
PLANE BUCKLING MODELS

derivation of equations for the existing model is given in Figure 4-7.

In computing slab lengths prone to buckling, the following should be noted:

a) The slab lengths obtained is an upper limit to the height of a plane footwall under dry conditions.

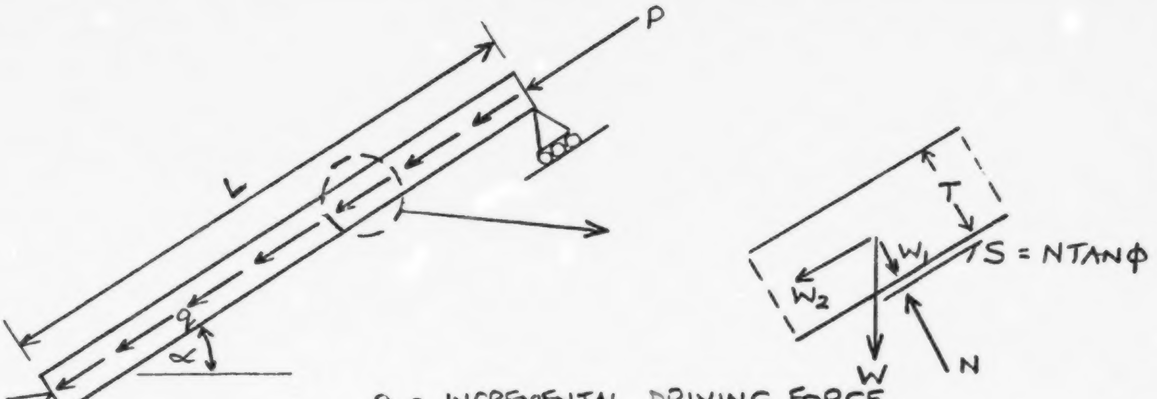
b) The general experience in Western Canada has been that plane buckling failures tend to occur only for very thin (few centimeter thick) slabs, typically with low deformation modulii. For thicker slabs, other failure mechanisms typically occur prior to the on-set of plane buckling.

With respect to water pressures, Cavers (1981) presented a 3 hinge buckling failure analysis for plane slopes including this aspect. Results of this analysis indicated that:

a) The maximum water pressure which a slope can sustain under the 3 hinge failure mechanism increases with height of slope. This is due to the increase in the restoring moments on the square ends of the blocks with increase in slope height.

b) For lower slopes or for high slopes in which high shear strengths exist along bedding due to cohesion or rock bridges, the allowable water pressures at the toe are considerably lower.

These results lead to a somewhat paradoxical condition with respect to groundwater pressures, and should not be relied upon



q = INCREMENTAL DRIVING FORCE
W = INCREMENTAL SELF WEIGHT

ASSUMPTIONS:

1. COMPONENT OF SELF WEIGHT NORMAL TO BEDDING IS NEGLECTED (I.E. $W_1 = W \cos \alpha = 0$)
2. MOMENTS ON SLAB ENDS ARE NEGLECTED
3. TENSILE STRENGTH AND DISPLACEMENTS ARE NEGLECTED
4. SLAB ENDS ARE PINNED
5. DRY, COHESIONLESS CONDITIONS.

$$q = W_2 - W_1 \tan \phi$$
$$= \gamma T \sin \alpha - \gamma T \cos \alpha \tan \phi$$ PER UNIT WIDTH, PER UNIT LENGTH

$$\therefore q/T = \gamma(\sin \alpha - \cos \alpha \tan \phi) \text{ ------------------ } (1)$$

MOMENT OF INERTIA, $I = \frac{T^3}{12}$ PER UNIT LENGTH

FROM TIMOSHENKO & GOODIER (p.107):

$$P = \frac{mEI}{L^2}$$

WHERE $m = -4.94n + \pi^2$

AND $n = \frac{qL^3}{\pi EI}$

WHERE E = ELASTIC (YOUNG'S) MODULUS

PUTTING $P=0$, AND SUBSTITUTING FOR m & n GIVES

$$L^3 = \frac{\pi^4 EI}{4.94q}$$
$$= \frac{KEI}{q}$$ WHERE $K = \frac{\pi^4}{4.94} = 19.72$ (CONSTANT)

$$\therefore \frac{KI}{q} = \frac{K}{q}\left(\frac{T^3}{12}\right) \text{ ------------------ } (2)$$

$$L = \sqrt[3]{\left(\frac{KI}{q}\right)E} \text{ ------------------ } (3)$$

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FIGURE 4-7
FORMULAE FOR BUCKLING OF PLANE
SLAB UNDER INCREMENTAL AXIAL LOADING

SCALE NTS | DATE 10/86 | MADE GJB | CHKD. MG | JOB: VG03957 | PLATE –

for day-today operation of a footwall. In particular, it may be difficult to determine whether the existing stability of a plane footwall is the result of low water pressures, or to high in-plane axial stresses. We recommend that in all cases, the conservative approach be used, and that drainage be provided on the footwall to minimize water pressures as much as possible.

Figure 4-8 shows a stability chart constructed using the updated plane buckling model. Results are obtained in terms of slab length, which may be converted to slope height by means of the slope angle. This design chart is constructed for dry conditions, and does not consider the presence of cohesion along bedding. The presence of cohesion could be modeled by decreasing the axial load per unit thickness in Graph 1 (Figure 4-8) by an amount corresponding to the cohesive force per metre on the slope, divided by the unit thickness of the slab.

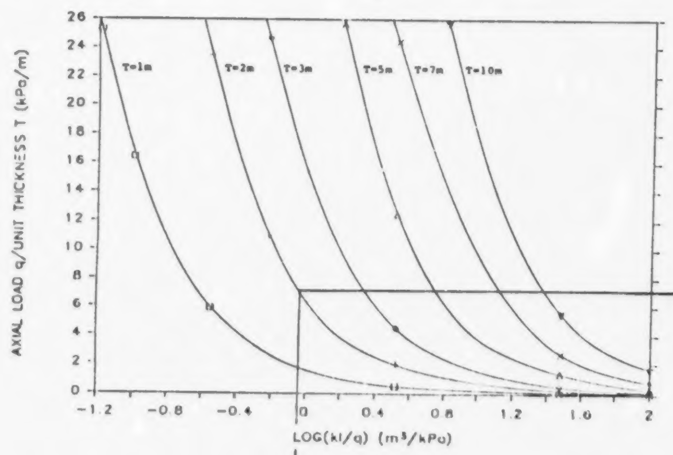
4.3.2 Curved Slabs

4.3.2.1 Introduction

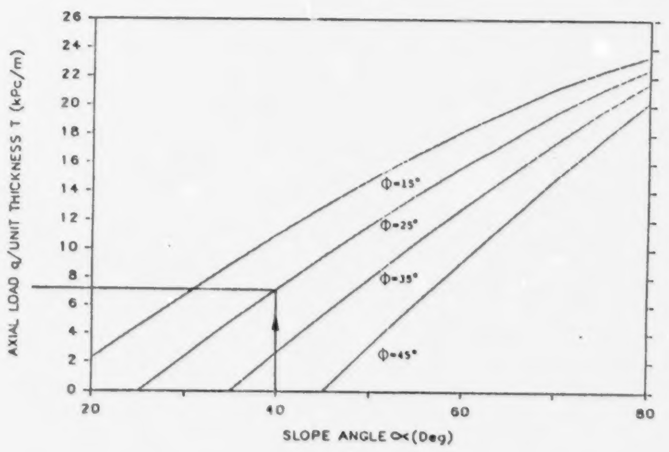
The buckling of curved slabs, illustrated on Figure 4-1, has been observed in a number of Western Canadian mines. The curvature of the slab may range from very tight curves with radii of a few metres to very long radius curves, such as the overall form of the Line Creek footwall (see Chapter 6).

Together with translational failure modes, buckling failure modes form a major constraint on footwall operating height in the absence of mitigative measures. Failure modes observed in Western Canada have included failures of slabs on tight rolls, failure of

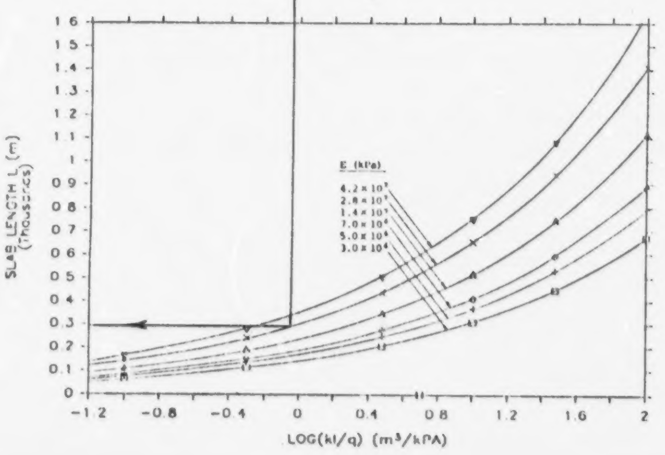
2

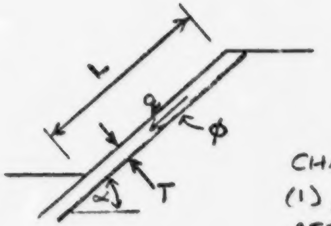


1



3





ϕ = ANGLE OF SHEARING RESISTANCE ALONG BEDDING

E = ELASTIC (YOUNG'S) MODULUS

K = 19·72 (CONSTANT)

CHARTS ARE BASED ON EQUATIONS (1), (2) & (3) IN FIGURE 4-7. ASSUMPTIONS GIVEN IN FIGURE 4-7.

EXAMPLE : FOR $\alpha = 40°$, $\phi = 25°$, FROM CHART (1), $q/T = 7·14$.
FOR $q/T = 7·14$, T = 2m., FROM CHART (2), $KI/q = 0·92$.
FOR $KI/q = 0·92$, $E = 2·8 \times 10^7$ kPa, L = 295·41m.

THESE CHARTS ARE FOR $\gamma = 25$ kN/m³

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FIGURE 4-8
DESIGN CHARTS FOR PLANE BUCKLING
OF AN ELASTIC SLAB

more gentle rolls (see Cavers (1981)) and failure on symmetrical rolls. A major emphasis in this project has been to develop methods of analyzing curved footwall strata to increase understanding of mechanisms of failure of curved slopes, and to allow realistic predictions of footwall behaviour on curved slopes to be made. The methods developed in this project will allow better analysis of footwalls, particularly those exemplified by Line Creek, which exhibit an overall curvature in profile.

Two basic approaches have been taken to analyzing the buckling failure of curved slabs in footwall strata:

a) Simplified analysis, involving the development of design charts using buckling equations developed by Corbyn (1978). These equations tend to be conservative, due to the assumption of negligible slab thickness, but provide a simplified first approach to design.

b) Comprehensive analysis, involving the development of computer program CURVBUK, to allow the analysis of discrete 3 hinge buckling. This analysis takes into account anchor forces, water pressures and slab thickness. Details of this program are given in Appendix 'B'.

These methods of analysis are discussed in greater detail below.

4.3.2.2 Simplified Analysis

For this analysis, the following assumptions are made:

a) The slab thickness is infinitely thin. This results in a conservative analysis due to ignoring the restoring moments developed at the ends of a block of finite thickness. However, the resulting errors are considered small for rolls of large extent and for thin bedding.

b) Dry, cohesionless conditions.

c) The method is based on maintaining the radial stress, σ_r , greater than or equal to zero at the roll. No allowance is made for tensile strength of the footwall materials or for interactions between the plane and curved portions of the slope.

Using these assumptions, Corbyn (1978) has shown that the stability of the slope is governed by the following equation:

$$H < \frac{r \sin (90 - \alpha)}{1 - \tan \phi \tan (90 - \alpha)} \qquad (4\text{-}5)$$

where: H = Vertical slope height,
r = Roll radius,
α = Slope angle above the roll,
ϕ = Angle of shearing resistance.

On the basis of this equation, a series of stability charts have been developed for different values of friction angle, slope angle and roll radius. These are shown on Figure 4-9.

These charts permit a first approach to the stability of rolls or curved slopes where the slope or roll may be approximated by a

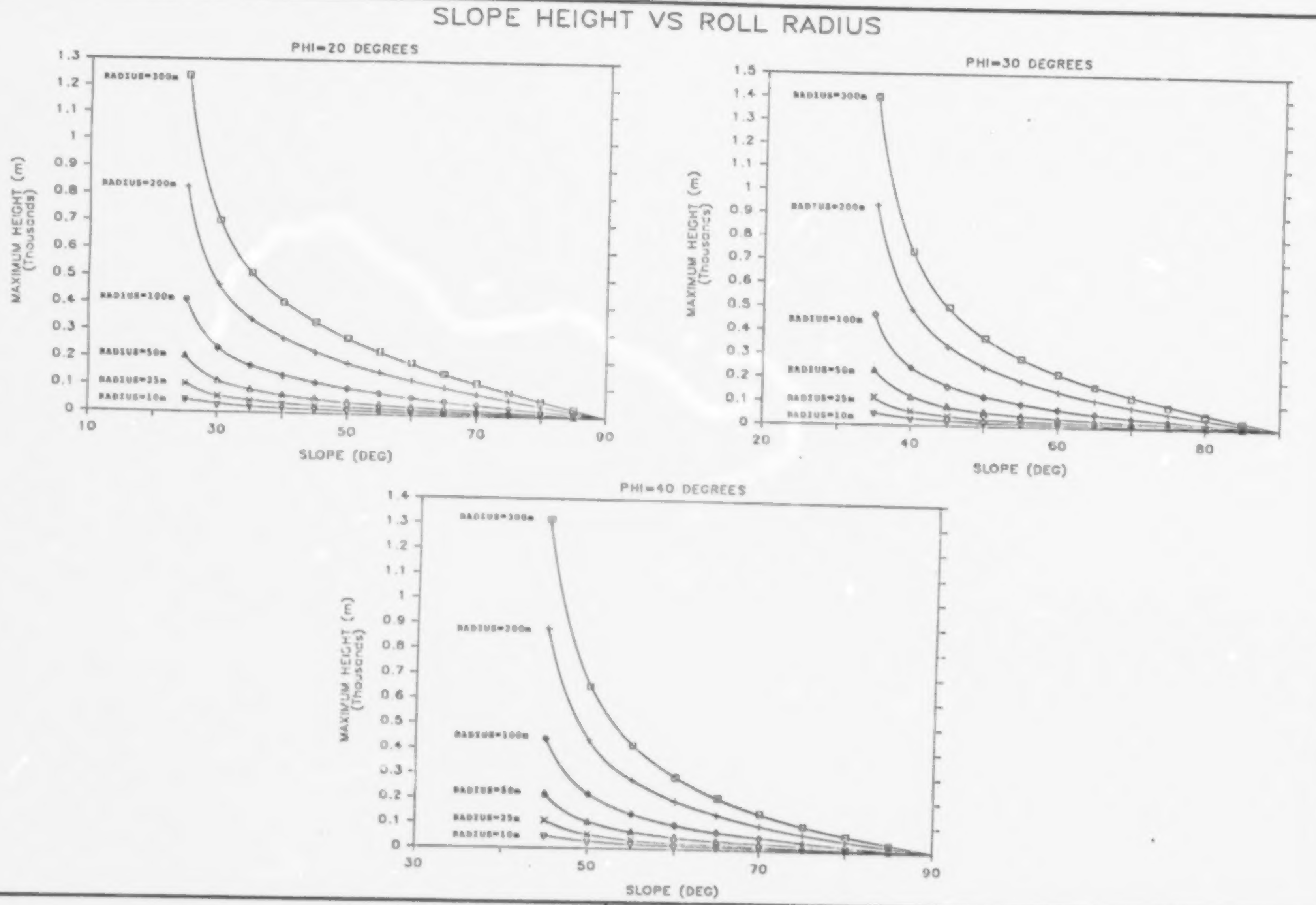

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FIGURE 4-9
DESIGN CHART FOR
DRY CIRCULAR CURVED FOOTWALLS
(CORBYN'S METHOD)

circular curve, the slope is plane above the roll or curve, and the slope is dry. These design charts should not be used for unusually thick footwall slabs (say greater than 2% of footwall height). The minimum deflection of the slope at the roll from the original trend of the slope should be equal to slab thickness. Slopes which do not fulfill these criteria may be better analyzed using either program CURVBUK or plane buckling methods.

Comparing the results of this analysis with those of CURVBUK, it is apparent that for rolls in which the change in dip of the slope is large (say from a slope of 40° to near vertical), Corbyn's equations are non-conservative due to the fact that the complete roll forms the lower block of a two block buckle and the lower block rotates forward in solid body rotation. Therefore, Corbyn's method should not be used in such instances.

Corbyn (1978) also derived the following equation to give the radial stress required to act on curved laminae in a rock slope to ensure stability:

$$\sigma_r > \Delta t\left(\frac{\sigma_\alpha}{r} - \gamma \cos \alpha\right) \qquad (3\text{-}6)$$

where: σ_r = Radial stress to be applied to roll surface,
Δt = Roll thickness (from surface to point where it dies out at depth),
σ_α = In-plane stress (driving force from slabs higher up the slope),
r = Radius of curvature of roll,
γ = Unit weight,
α = Slope angle at the roll.

The following expression, derived from the Mohr-Coulomb equation, considers the stresses acting on a block on an inclined plane.

$$\sigma_\alpha / H = \gamma(\sin\alpha - \cos\alpha \tan\phi) \qquad (3\text{-}7)$$

where: σ_α = Upslope stress on the block to ensure stability,
H = Block height.

Equations (3-6) and (3-7) can be used to provide a useful first approach to the determination of appropriate anchor stresses, and design charts based on these equations, and assuming a unit weight of 25 kN/m^3 are presented in Figure 4-10.

An example of the use of these charts is presented on the charts, and outlined below:

Assumed variable parameter values:

ϕ = 35°
α = 60°
r = 25 m
H = 200 m

CHART 1: This chart utilizes equation (3-7). Enter chart on x-axis (slope angle α, which in this example is 60°), and for a given ϕ (35°), determine the value of σ_α/H (y-axis). In this example, σ_α/H = 13 kPa/m slope height.

CHART 2: For a know value of σ_α/H and roll radius, r (in this case, 50 m), determine σ_α/rH (on x-axis). In the example, σ_α/rH = 0.25.

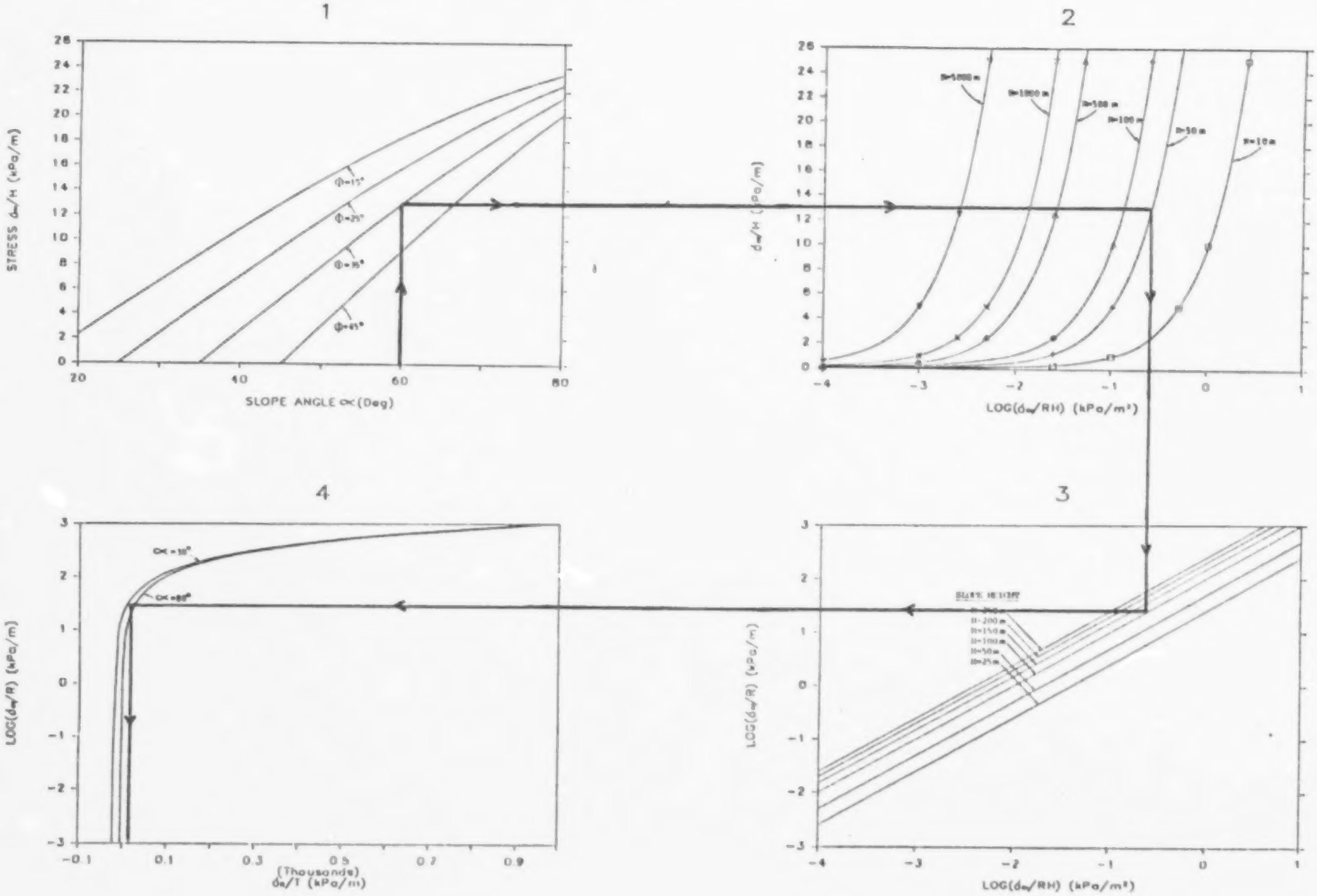

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FIGURE 4-10
DESIGN CHART FOR RADIAL BOLTING STRESS
FOR CURVED FOOTWALL SLOPES

CHART 3: For a known value of σ_α /rH and slope height, H (in this case, 100 m) determine σ_α /r. In this example, σ_α /r = 25 kPa/m.

CHART 4: This chart utilizes equation (3-6). From known values of σ_α /r and slope angle, α (in this case 60°) determine $\sigma r/\Delta t$. In this example, $\sigma r/\Delta t$ = 15 kPa/m roll thickness.

Thus, for the example given, a stress of 15 kPa must be applied to the roll for each metre of roll thickness.

This method of anchor stress determination is applicable to smaller rolls, but for large curved slopes, the value used for Δt may be much too large, and may result in impractical or impossible anchoring situations. Where Δt exceeds 5 to 10 m, program CURVBUK should be used in preference to Corbyn's method to establish anchoring forces. For some situations, the results will tend to be conservative, particularly for thicker slabs. However, the method does provide a useful first approach to the determination of appropriate anchoring stresses.

4.3.2.3 Comprehensive Analysis

This sections discusses the application of 3 hinge buckling methods to the determination of the stability of a curved slab on a slope. Three hinge buckling methods have been applied to roof rock in underground openings by Chugh (1977) and to footwall slopes by Cavers (1981). The present approach is a development of ideas contained in Cavers (1981) to the point where a "user friendly" computer program has resulted. The program is written and compiled in Turbo Pascal Version 3.0 and will run on any IBM PC or compatible machine. The general methodology of the program and results are discussed briefly below. Appendix 'B' provides detailed documentation of the equations used. The general configuration analyzed by CURVBUK is shown in Figure 4-11, and an example of the input screen is shown in Figure 4-12. Data may also be input under a question and answer procedure if only a single run is desired.

The program is extremely versatile, allowing calculation of the stability of virtually any 3 hinge buckle configuration. For a plane block driving one or two curved blocks, where the curved blocks are portions of a circle, the program automatically calculates weights, moments, water forces and the angle of application of the forces. For non-circular cases, all variables may be input explicitly.

The main advantage of CURVBUK over Corbyn's method, is that the thickness of the slab is considered, which gives more realistic results for long radius rolls. In addition, water forces and other external forces can also be included. Solid body rotations of the entire roll can be properly modelled, avoiding non-conservative results for large deflection rolls. To date, several hundred runs with the program have been made, resulting in significant gains in the understanding of the mechanism of buckling of curved slopes.

One of the biggest gains in understanding has been in the determination of a realistic and appropriate buckling failure mechanism. Figure 4-13 shows typical buckling failure mechanisms for various types of structure. In analyzing a slope, it is necessary to pick the failure mechanism which produces the lowest failure load. This process is analogous to finding the critical slip surface during

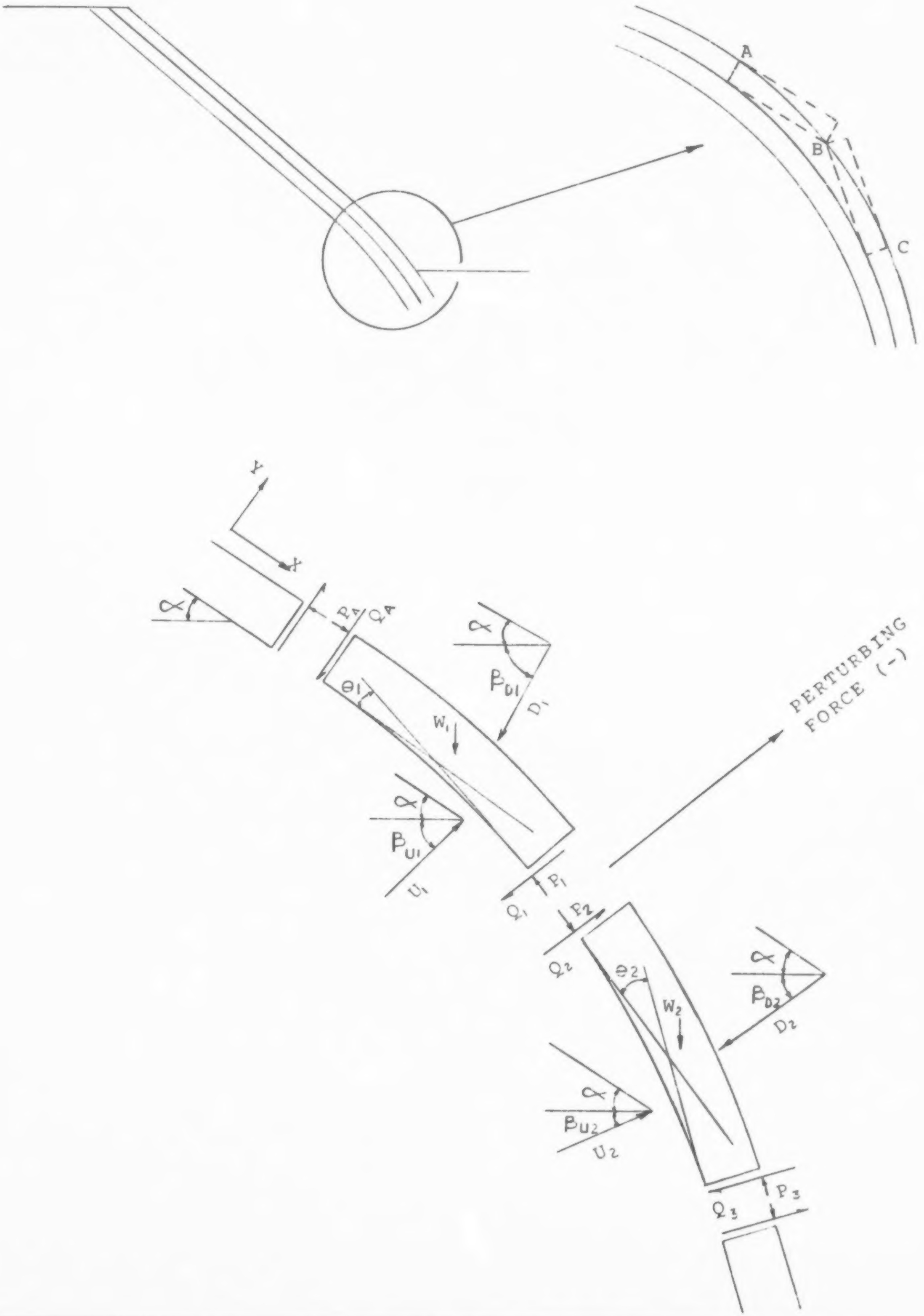
A
B
C
Y
X
α
P_A
Q_A
α
β_{D1}
D_1
θ_1
W_1
PERTURBING FORCE (-)
α
β_{U1}
U_1
P_1
Q_1
P_2
Q_2
θ_2
W_2
α
β_{D2}
D_2
α
β_{U2}
U_2
Q_3
P_3

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FIGURE 4-11
GENERAL CONFIGURATION ANALYSED
BY PROGRAM "CURVBUK"

SCALE NONE
DATE 8/86
MADE MG
CHKD. GJB
JOB: VG03957
PLATE

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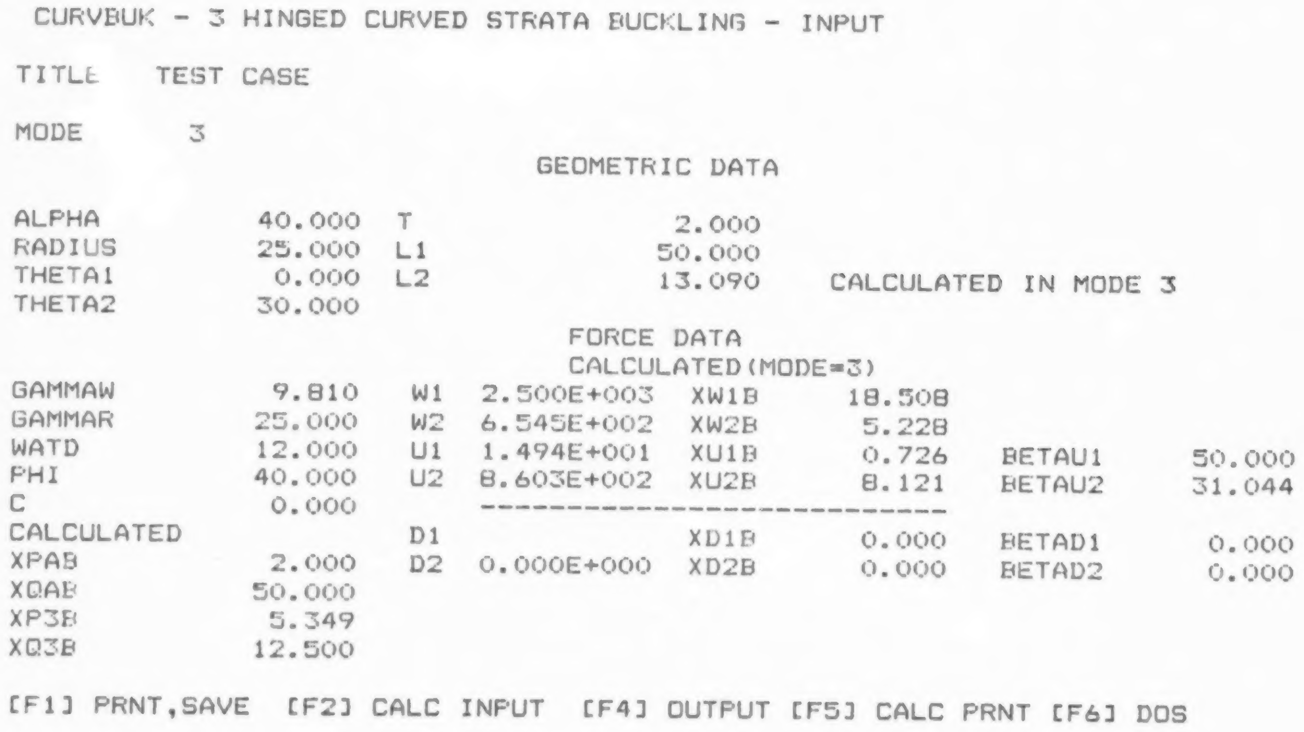

```
CURVBUK - 3 HINGED CURVED STRATA BUCKLING - INPUT

TITLE    TEST CASE

MODE       3
                                  GEOMETRIC DATA

ALPHA          40.000  T                2.000
RADIUS         25.000  L1              50.000
THETA1          0.000  L2              13.090    CALCULATED IN MODE 3
THETA2         30.000
                                   FORCE DATA
                                   CALCULATED(MODE=3)
GAMMAW          9.810   W1  2.500E+003  XW1B      18.508
GAMMAR         25.000   W2  6.545E+002  XW2B       5.228
WATD           12.000   U1  1.494E+001  XU1B       0.726   BETAU1       50.000
PHI            40.000   U2  8.603E+002  XU2B       8.121   BETAU2       31.044
C               0.000       ---------------------------
CALCULATED              D1              XD1B       0.000   BETAD1        0.000
XPAB            2.000   D2  0.000E+000  XD2B       0.000   BETAD2        0.000
XQAB           50.000
XP3B            5.349
XQ3B           12.500

[F1] PRNT,SAVE  [F2] CALC INPUT  [F4] OUTPUT [F5] CALC PRNT [F6] DOS
```

EXAMPLE OF INPUT SCREEN FOR PROGRAM "CURVBUK". ALL DATA MAY BE CHANGED IN ANY ORDER. VARIABLES AND MODES ARE DEFINED IN APPENDIX B.

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FIGURE 4-12
EXAMPLE OF INPUT SCREEN
FOR PROGRAM "CURVBUK"
MODE 3

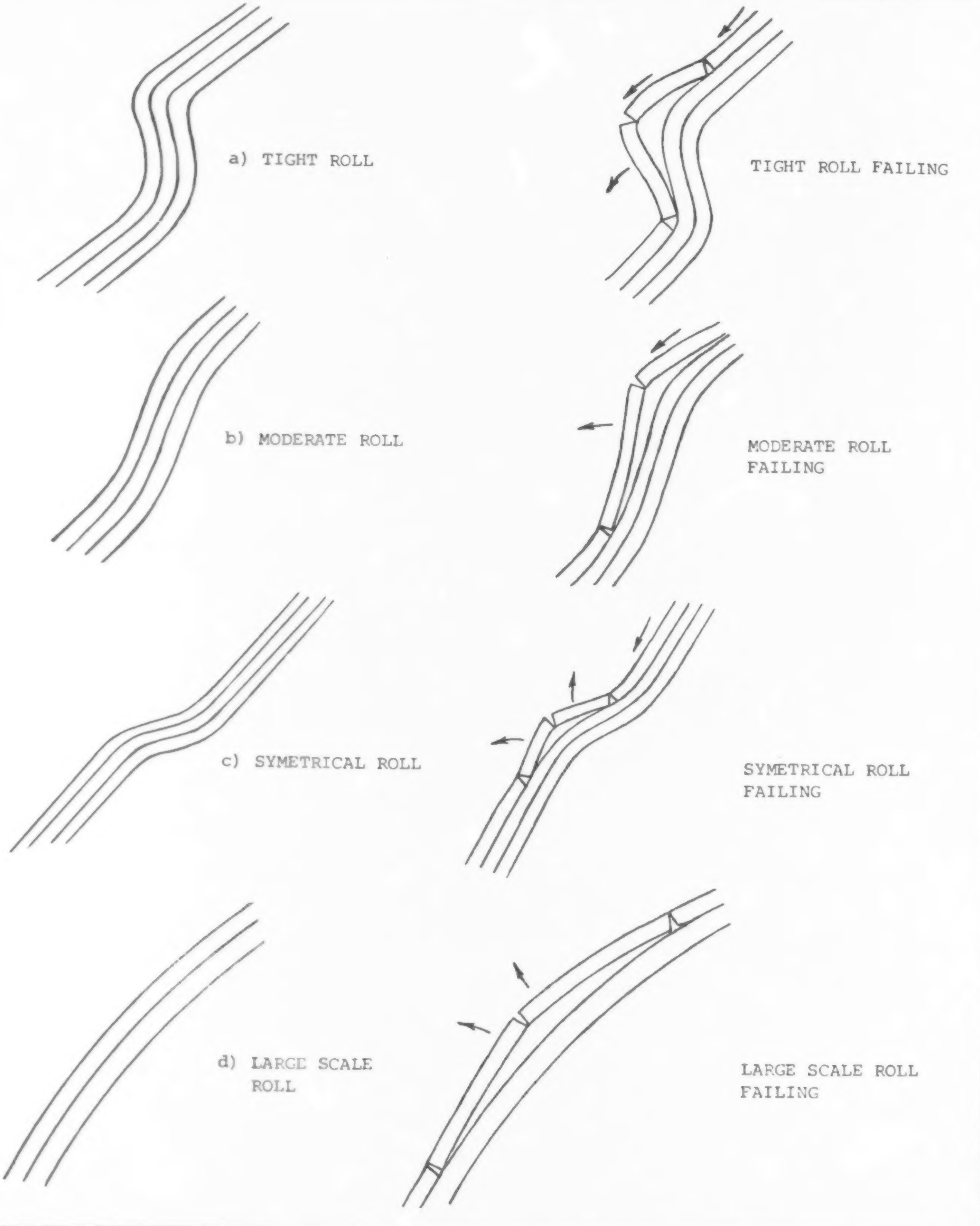
a) TIGHT ROLL
TIGHT ROLL FAILING
b) MODERATE ROLL
MODERATE ROLL FAILING
c) SYMETRICAL ROLL
SYMETRICAL ROLL FAILING
d) LARGE SCALE ROLL
LARGE SCALE ROLL FAILING

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FIGURE 4-13
TYPICAL MECHANISMS OF
BUCKLING FAILURE OF ROLLS

SCALE N.T.S	DATE 09/86	MADE M.G.	CHKD. D.S.C	JOB: VG03957	PLATE

HT12 - 79/05

conventional translational slope stability analysis. Guidelines for picking critical buckling failure mechanisms, based on experience using CURVBUK, are as follows:

a) Asymmetrical roll: This situation is shown in Figure 4-13a and 4-13b. The lower block between the inflection points of the roll is pushed outward from the slope by the upper, relatively plane block. Model testing and runs with program CURVBUK confirm that there is no tendency for the slope to buckle with a hinge point in the middle of the roll. Rather, the preferred mode of failure is a planar block pushing the lower curved block.

b) Symmetrical rolls: See Figure 4-13c. These tend to fail symmetrically with the hinge point between the upper and lower block at the center of the roll.

c) Large scale rolls: Typically, the failure looks similar to Figure 4-13c, but it may vary depending on the roll type.

In addition, runs with program CURVBUK and model testing suggest that if the failing blocks are dissected by frequent cross joints, the upper and lower blocks will still move as units having lengths close to their critical lengths (lowest factor of safety). After failure is initiated, the blocks will then disintegrate into the smaller units as determined by cross joints. Thus, the length of the blocks should be determined by analysis, and not set to the shortest interval between two cross joints.

An example of output using CURVBUK is given in Figure 4-14. The program applies an outward perturbing force to the center hinge

```
TEST CASE
   THREE HINGED BEAM IN BUCKLING MODE
9/19/1986
14:48:6

                         MODE                  =     3

                         THICKNESS OF SLAB  =        2.00
                         SLOPE ABOVE ROLL   =       40.00
                         SLOPE BELOW ROLL   =       70.00
                         GAMMA ROCK         =       25.00
                         GAMMA WATER        =        9.81
                         VERTICAL WATER DIST=       12.00


                         PHI AND C FOR CROSS JOINTS:
                               PHI          =     40.00
                               C            =     0.00E+000

                         RADIUS OF CURVATURE=       25.000

                         INPUTTED THETA ANGLES:
                               THETA1       =      0.00
                               THETA2       =     30.00

                         INPUTTED BLOCK LENGTHS:
                               LENGTH 1     =     50.00



                       THE FOLLOWING DATA HAS BEEN CALCULATED:

                       CALCULATED BLOCK LENGTHS:
                             LENGTH 1       =       50.000
                             LENGTH 2       =       13.090
                       CALCULATED BLOCK WEIGHTS:
                             W1             =    2500.000
                             W2             =     654.498
                       CALCULATED WT MOM ARMS:
                              XW1B            =       18.508
                              XW2B            =        5.228
                       CALCULATED WATER PRESSURE FORCES:
                              U1              =    1.49E+001
                              U2              =    8.60E+002
                       CALCULATED WATER MOM ARMS:
                              XU1B            =        0.726
                              XU2B            =        8.121
                       CALCULATED BETA ANGLES:
                             BETAU1         =       50.000
                             BETAU2         =       31.044
                       CALCULATED FORCE MOM ARMS:
                              XPAB            =        2.000
                              XQAB            =       50.000
                              XP3B            =        5.349
                              XQ3B            =       12.500


 FDISTURB      P1          Q1          PA          QA          P3          Q3
0.000E+000 9.756E+003 -1.30E+003 8.149E+003 -5.99E+002 9.550E+003 4.372E+003
-1.58E+002 7.780E+003 -1.14E+003 6.173E+003 -6.78E+002 7.720E+003 3.589E+003

SLOPE IS CONDITIONALLY STABLE-P1 IS MAXIMUM

EXAMINE THE MAGNITUDE OF THE PERTURBING FORCES TO
DETERMINE THE DEGREE OF STABILITY
```

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FIGURE 4-14
EXAMPLE OF OUTPUT
FOR PROGRAM "CURVBUK"
MODE 3

SCALE ______ DATE 09/86 MADE MG CHKD. DSC JOB: VG03952 PLATE ______ between the two blocks to determine the stability condition of the slope (Figure 4-11). The possible results are as follows:

a) "Slope is Stable": This implies that force P_1 is less than zero, and that when the perturbing force is applied, P_1 increases to zero and then becomes positive. Thus, to put the block system into a state of limiting equilibrium, the slope has to have a "tensile" force applied, indicating that the system is stable under all conditions of slope height.

b) "Slope is Conditionally Stable - P_1 is Minimum": This implies that P_1 is greater than zero, and that when the perturbing force is applied, P_1 decreases. This indicates that at least this value of P_1 (or the corresponding slope height above) must be present in order to produce stability. This condition is normally encountered when water pressures are included, and results from requiring a certain minimum resisting moment to counteract the outward water pressure thrust. This situation can be dangerous if there is cohesion present in the slope, and the value of P_1 existing in the field is less than that determined by analysis. Under such conditions, the slope would fail.

c) "Slope is Conditionally Stable - P_1 is Maximum": This indicates that when the perturbing force is applied, P_1 decreases. The value of P_1 is the maximum which the roll can support.

d) "Slope is Unstable": The analyzed slope is unstable under all conditions, and will not support any driving force (P_1) whatsoever. P_1 may be negative.

These various interactions arise from the different loading conditions which are possible, combined with the restoring moments that exist on the blocks due to their finite thickness. The desirable design conditions are for complete stability, or for P_1 being a minimum.

Tables in Appendix 'B' provide results of numerous stability analysis using program CURVBUK for slopes of initial slope angles of 40°, 55° and 70°. The tables are constructed with the following assumptions:

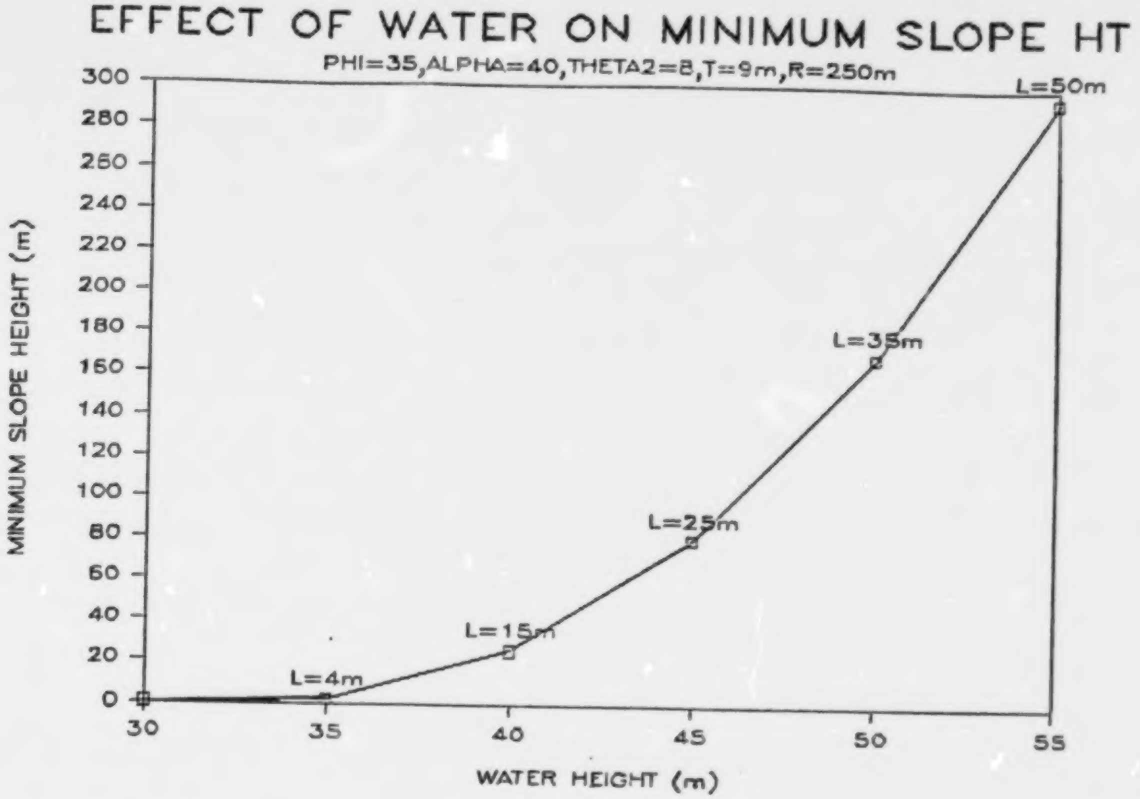
a) The slope is dry.

b) Values of P_1 shown are maximum values. That is, slopes which are higher than the corresponding height for this P_1 value would be expected to drive the buckle to failure. At the end of Appendix 'B', Figures B-1, B-2 and B-3 are included which permit the calculation of driving force for cohesionless slopes under dry conditions.

c) Where the slope is stable, the value of perturbing force which would cause failure for $P_1 = 0$ has been computed using $L_1 = 5$ times slab thickness. This is somewhat arbitrary and may not be the critical value. Hence, this computation is, at best, an approximation. The perturbing force may be converted to a water pressure or seismic force to give some idea of the degree of stability of the slope.

As an example of a current application of program CURVBUK, Figure 4-15 shows the results of calculations made for a roll below the existing pit floor at Line Creek, which will be uncovered in the coming months. These geometrical conditions are based on the existing knowledge of the configuration of the roll, and could be revised when the roll is uncovered during mining. The calculations show that under dry conditions, the roll is stable. When water pressures are applied, a certain minimum slope height above the roll is required in order to produce stability. ("Slope conditionally stable - P_1 minimum") This indicates that a minimum driving force is required to produce the necessary restoring moment on the blocks, to resist the water pressure thrust. As the water pressure increases, the minimum slope height increases. Critical values of L1 for each case analyzed are also shown in Figure 4-15. These cases are selected from a much larger number of runs to determine the critical values for L1 in each instance. The results indicate that the slope is stable under dry conditions, or very likely to be stable under low head conditions (for example, water pressures equivalent to one bench height). Instability would occur if high water pressures exist.

A second example of the use of program CURVBUK is demonstrated in Figure 4-16, in which the results of calculations to determine the required anchoring force to resist water pressures of various magnitudes are presented. These calculations are not based on any particular configuration at Line Creek, and are presented for example purposes only. Due to the large number of different variables, it is not possible to produce a general slope stability design chart incorporating anchor forces and groundwater pressures - several hundred different charts would be required for this purpose.



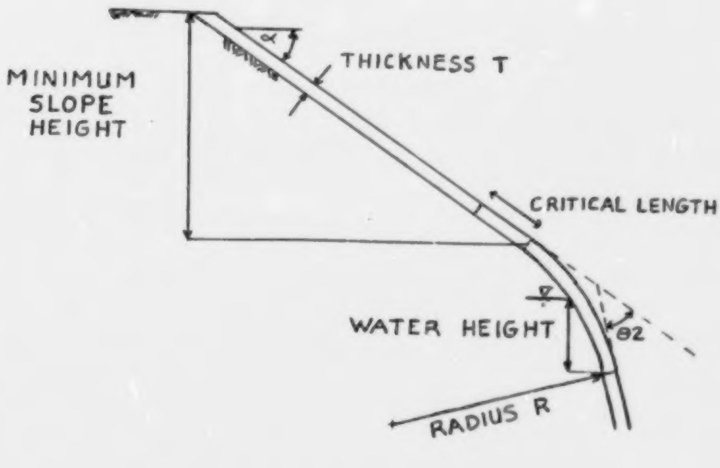

MINIMUM
SLOPE
HEIGHT
α
THICKNESS T
CRITICAL LENGTH L
WATER HEIGHT
θ2
RADIUS R

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FIGURE 4-15
EFFECT OF WATER ON SLOPE HEIGHT
FOR 3-HINGED BUCKLING OF CURVED SLOPES

SCALE N.T.S. | DATE 09/86 | MADE M.G. | CHKD. DS.C | JOB: VG03957 | PLATE

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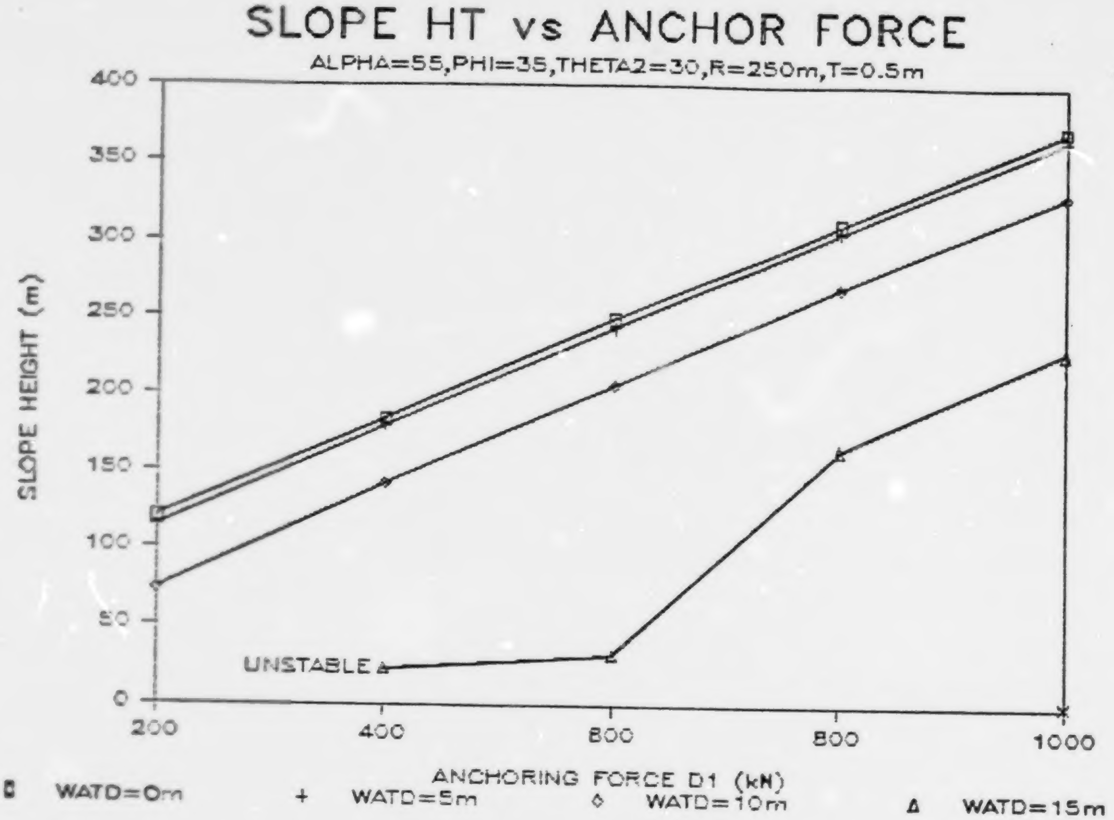

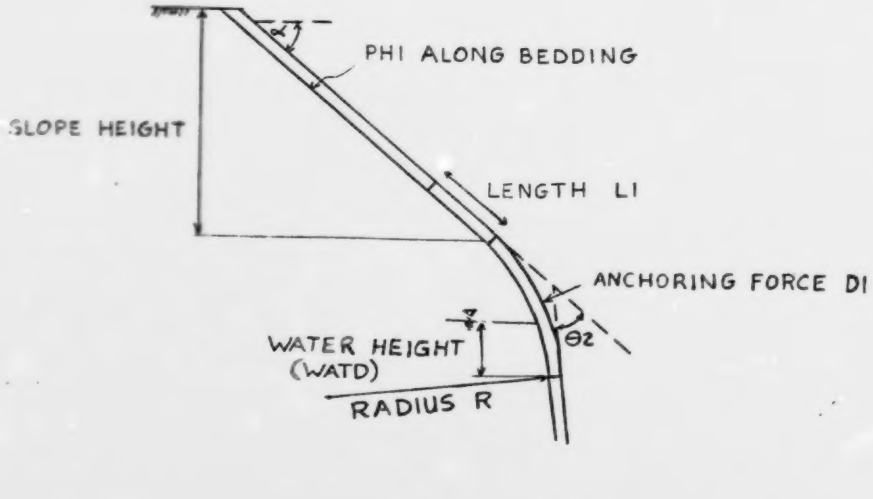
α
PHI ALONG BEDDING
SLOPE HEIGHT
LENGTH L1
ANCHORING FORCE D1
θ2
WATER HEIGHT
(WATD)
RADIUS R

HARDY ASSOCIATES (1978) LTD.
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FIGURE 4-16
EFFECT OF ANCHORING FORCES ON SLOPE HEIGHT
FOR 3-HINGED BUCKLING OF CURVED SLOPES

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The presented examples merely show the range of capabilities of the program.

As previously stated, the stability of a curved slab is complex due to the large number of different variables which may interact on a given slope. Nevertheless, it is now possible to make reasonable predictions about the behaviour of a curved slab, providing that data on the geometry and slab thickness is available. In evaluating data from program CURVBUK, it should be remembered that the program assumes that individual blocks will not fail internally during initial movement. This implies that adequate rock strength is present to resist the forces imposed on the blocks, that cross joints on the blocks are perpendicular to bedding, and that bedding is not disrupted either by natural features, such as pinchouts, or by additional fracturing from excessive blasting.

5.0 DESIGN IMPLEMENTATION AND OPERATIONAL CONSTRAINTS

5.1 INTRODUCTION

Following the completion of appropriate analytical techniques, implementation of the design recommendations (in the form of drainage, support, excavation or any combination thereof) is likely to be affected by various operational constraints and practices. These parameters have a major influence on the overall stability of the footwall and on the success of the mitigative measures.

Natural drainage characteristics and the optimum use of artifical drainage, blasting practice and procedures, excavation sequencing, anchor selection, installation and optimum orientation, and benching are considered in the following sections in relation to appropriate design implementation.

5.2 DRAINAGE

It is considered that under most mining situations it is desireable to reduce water pressures within near surface footwall strata to near zero. With respect to instituting a drainage program to meet this objective, there are several important points to consider:

a) Due to stress relief and axial loading characteristics of the footwall strata, bedding joints tend to open slightly, providing access for surface water along the footwall slabs.

b) Drainage out of the footwall along joints perpendicular and dipping in the opposite direction to the footwall (joints at A in Figure 5-1) is poor, since these joints are closed by in-plane stresses within the footwall slabs. Higher permeabilities are likely on the third orthogonal joint set (Set B in Figure 5-1), as these joints are typically not closed by high in-plane stresses along the footwall. The degree of natural drainage which is present is often a function of the numbers of the "B" type joints present on the wall.

c) The quantity of water along the bedding surface which causes high piezometric pressure may be very small, since the aperture of the bedding joints may be less than 1 mm. Thus, drains which are successfully reducing high water pressures may do little more than drip. The success of the drainage program should be judged on piezometric pressures measured with fast acting transducers (electrical or pneumatic) rather than on the amount of water encountered within the drains (see Section 3.5).

The problem of using natural drainage is that it may be overwhelmed by high transitory water pressures occurring during spring melt or heavy rainfall events. On many footwalls, it appears that much of the water along bedding originates from recharge where the bedding surfaces daylight near the crest of the slope. Due to the possibility of high transitory water pressures, it is recommended that drainage be installed on all footwalls, even where natural drainage is apparently successful in reducing groundwater pressures.

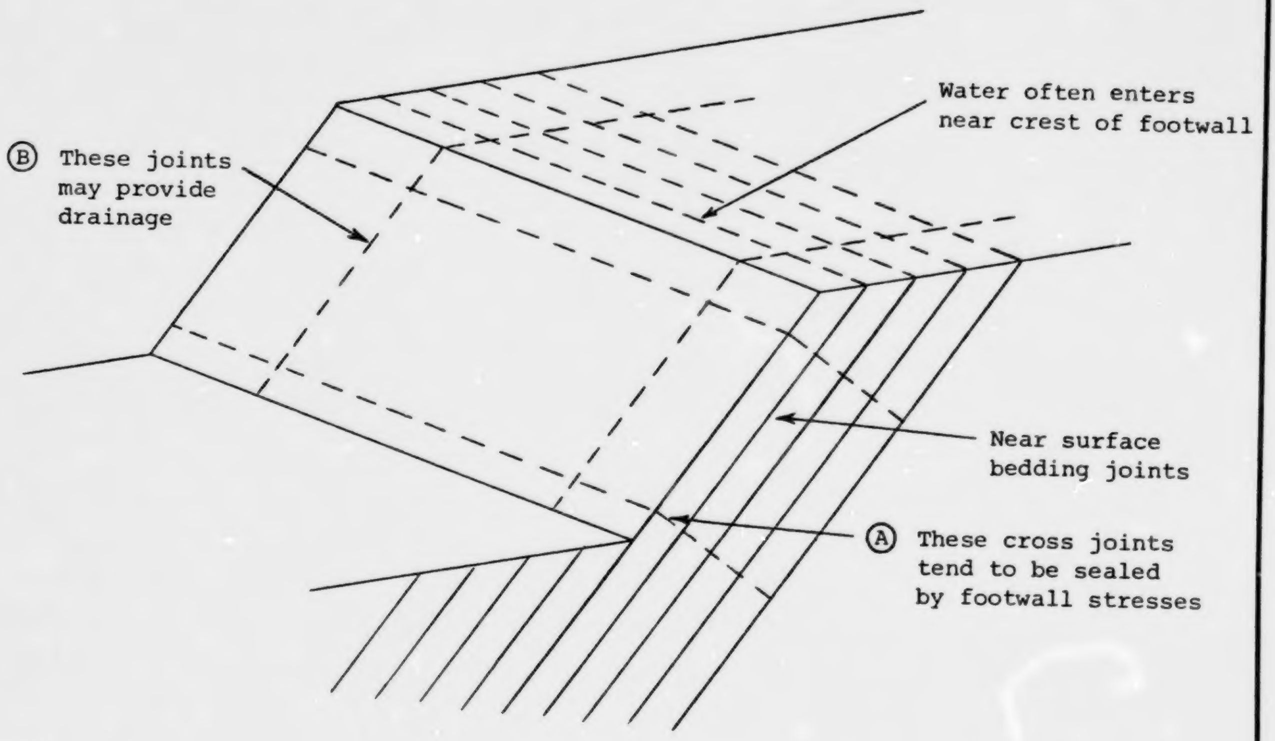
Water often enters near crest of footwall
Ⓑ These joints may provide drainage
Near surface bedding joints
Ⓐ These cross joints tend to be sealed by footwall stresses

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FIGURE 5-1
NATURAL DRAINAGE VIA JOINTS

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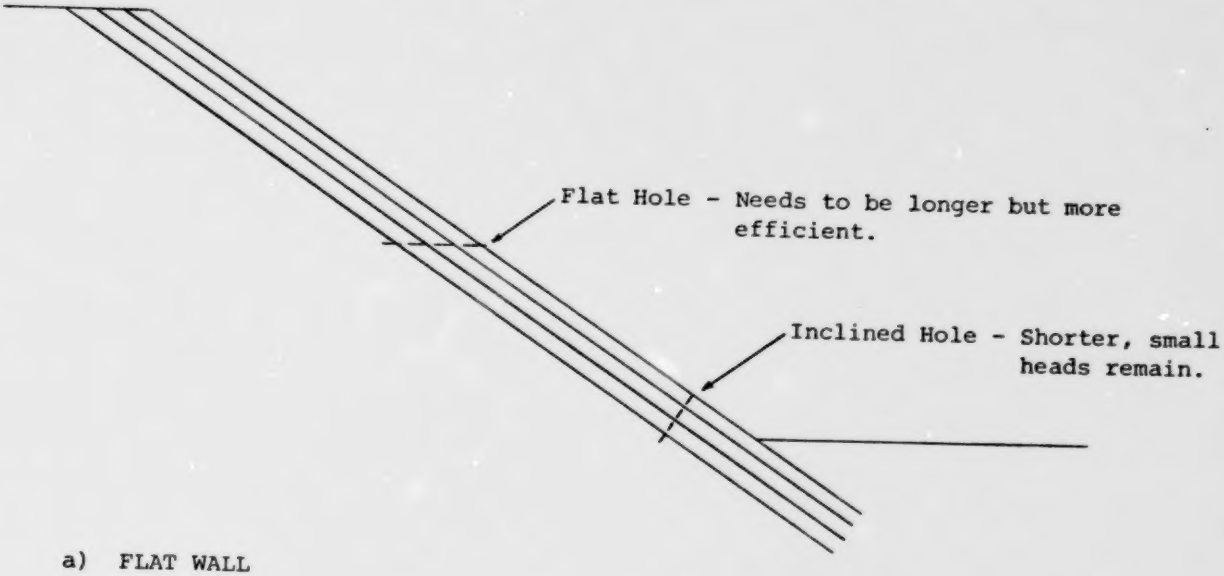
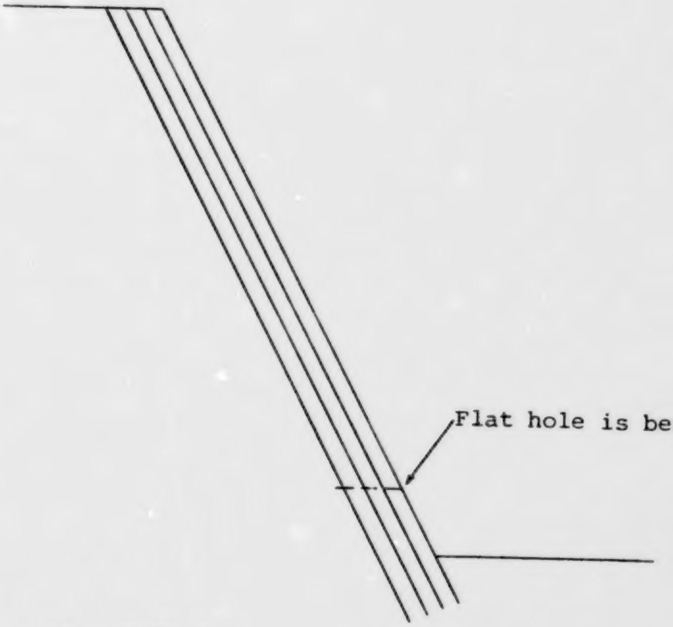
Only the lowermost line of drainage holes, along a footwall face a short distance above the pit floor, are normally successful in providing positive drainage of strata immediately behind the face. Higher up the slope, drains may intersect small volumes of water, but they are unable to lower water pressures near the toe of the wall. Moreover, there is a greater chance that drains higher up the slope will be in an unsaturated flow regime, thus making it difficult to get water into the drains. An exception occurs, of course, where the drains tap deeper aquifers.

Some consideration should be given to the angle that drain holes are drilled (Figure 5-2). The most desireable holes to promote positive drainage are inclined upwards from the horizontal at 5 to 15°. However, on a comparatively flat lying wall (sloped less than 30 to 40°), these drain holes are relatively inefficient in terms of length. On these relatively flat lying walls it may be preferable to drill an ongoing series of holes perpendicular to the wall near the toe. These downward inclined drill holes will provide very little dewatering or depressurization once they are high on the slope; rather, their function is to provide depressurization near the toe and not permit water pressures to escalate higher up the slope. For steeply dipping walls, the flat or gently inclined upwards hole is preferable.

Where the drainage philosophy is to maintain active drain holes near the toe of the slope to provide continued ongoing depressurization, it may not be necessary to line these holes, providing that the rock does not weather or break down and plug the hole. Inasmuch as these drain holes are near the toe of the slope, there is little tendency to recharge strata down slope (below the pit floor) if they are already saturated. PVC casing or drain pipes should definitely be used where appreciable water flows are tapped behind the footwall which might provide continual recharge to near surface strata, or


Flat Hole - Needs to be longer but more efficient.
Inclined Hole - Shorter, small heads remain.

a) FLAT WALL


Flat hole is best choice.

b) STEEP WALL

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FIGURE 5-2
DRAIN HOLE STRATEGIES

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where hole caving is a problem. For the flatter, gently inclined upwards holes, PVC casing with one or more rows of slots located on the upper circumference of the pipe may be used. The lower circumference of the pipe should be left unslotted to provide a trough for water to run in once it enters the pipe. Steeply inclined downward holes (near perpendicular to bedding) may be lined with pipes slotted all around.

Where it is necessary to rapidly reduce pressures along bedding, vacuum drainage (Brawner and Pakalnis, 1984) may be considered.

Use of packer testing has been discussed in this report to determine ranges of permeability along bedding. In examining these test results, it should be rememberd that the test measures permeability of the rock mass. The transmissivity of an individual fracture will be far higher, depending upon the fracture density included in the packer test zone, than the mass permeability determined from the packer test calculations. Thus, the groundwater pressure response to precipitation on a footwall may be relatively quick. This was found to be the case at Line Creek (see Chapter 6). This implies that unless comparatively intense monitoring is undertaken, it may be difficult to measure high transitory water pressure events. For this reason, a relatively conservative approach to drainage is recommended.

5.3 BLASTING PRACTICE

Blasting damage may precipitate failure of footwalls. We recommend that the following be considered in designing blast patterns near to footwalls:

a) Blast holes should not penetrate the coal seam, maintaining the coal seam as a buffer against the bottom charge of the hole.

b) Toe charges should be reduced as much as possible to avoid damage to the underlying footwall.

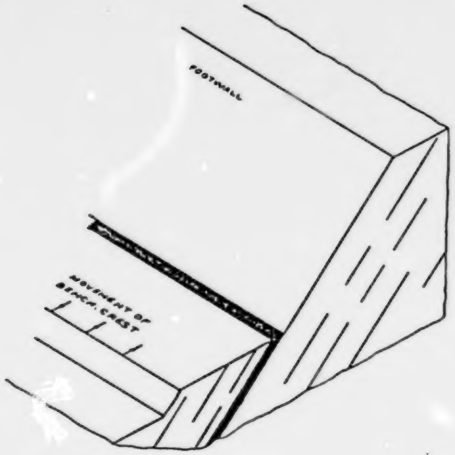
c) When blasting close to the footwall, it is preferable to blast to a free face which strikes perpendicular to the footwall. This avoids simultaneous acceleration of a long strike length of the footwall, thus reducing damage.

d) Charge per delay should be reduced as much as possible.

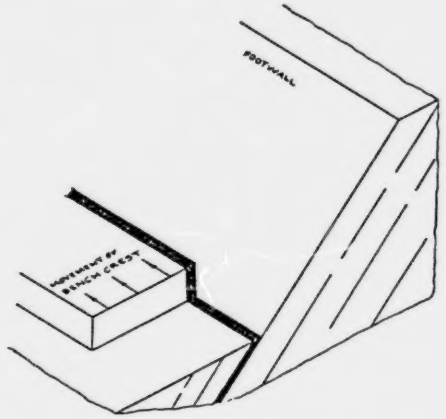
e) The buffer row should be used close to the footwall to reduce charge per delay in this area.

5.4 EXCAVATION SEQUENCE

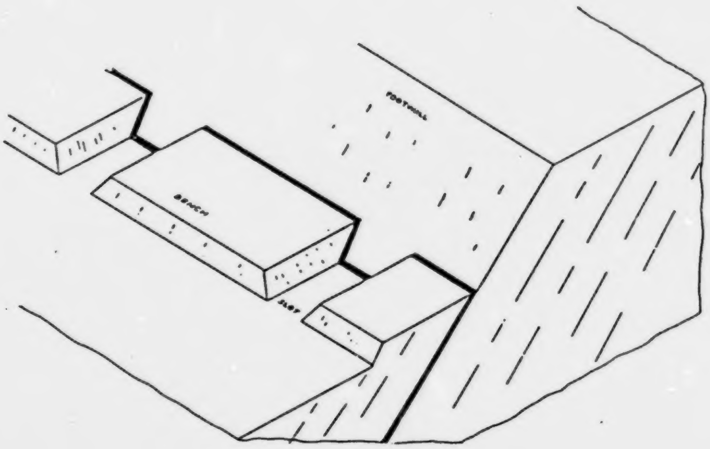
Figure 5-3 shows various excavation strategies which can be used close to the footwall. Simultaneous exposure of long lengths of the footwall is not recommended, to limit the effect of problem features exposed during the excavation process. Excavating a berm crest which moves along the footwall, exposes a small part of the footwall and allows conditions to be progressively checked during excavation of the lift. An alternative excavation strategy is shown on Figure 5-3c, in which slots are excavated to check conditions in potential problem areas. In both of the preferred excavation strategies (Figure 5-3b and Figure 5-3c), the blasted hanging wall rock adjacent to the footwall is used for temporary support during excavation.


FOOTWALL
MOVEMENT OF BENCH CREST

a) Excavation of bench crest toward footwall. This is a potentially hazardous practice close to the footwall since problem areas are daylighted simultaneously along the wall.


FOOTWALL
MOVEMENT OF BENCH CREST

b) Preferable mining method close to footwall. Footwall can be checked on an ongoing basis. If problem areas are detected, there is still some support available.


FOOTWALL
BENCH
SLOT

c) Alternative excavation strategy to check possible problem areas

NOTE Drawings from Cavers (1978)

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FIGURE 5-3
EXCAVATION STRATEGIES

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5.5 ANCHORING

5.5.1 Introduction

Anchoring is a commonly used mitigative measure on footwalls. The purpose of this section is to discuss briefly some of the special considerations for anchoring on footwalls, compared to anchoring practice elsewhere in an open pit mine. Additional discussion of anchoring strategies and various types of anchors which are available is contained in Hoek and Bray (1981), Goodman (1980) and Littlejohn and Bruce (1977).

Special considerations apply to the choice of rock anchors or dowels for use on a footwall. These special considerations are discussed in the following paragraphs.

5.5.2 Choice of Anchor

Table 5-1 outlines various anchor types which may be considered for footwalls. Based on considerable experience in the installation and use of these various anchor types, it is recommended that the use of grouted bars or cable anchors is the only practical choice where very thick footwall slabs occur. The anchors may be installed either as dowels or tensioned grouted anchors. We consider the installation of a tensioned anchor to be preferable since it allows a test of the anchorage to be made.

TABLE 5-1: POSSIBLE ANCHOR CHOICES FOR FOOTWALLS

TYPE	SUPPLIER	MAX. LENGTH	ANCHOR TYPE	REMARKS	REFERENCE
Grouted bar or cables	Several	Large	Grouted	May be installed as tensioned anchor using 2 stage grouting or as untensioned dowel. Shovel cable used very successfully by Line Creek.	
Polyester resin with bar	Several	10 m	Resin	Either a second stage resin or grout may be used for corrosion protection.	
Mechanical anchor on bar	Several	6 - 8 m	Mechanical	May be grouted after tensioning. Williams supplies "Hollow Core" Bar to facilitate grouting.	
Split-Set	Ingersoll-Rand	< 4 - 6 m	Friction (Continuous)	Life may be limited by corrosion. Galvanized split sets available. Provides drainage. Resistant to desplacement.	Tilman et al (1984)
Swellex	Atlas Copco	10 m	Friction (Continuous)	Expanded by high pressure water injection. Corrosion rate less than Split-Set. 10 ton design load.	Atlas Copco Bulletins

For intermediate thicknesses of slabs (1 to 2 m) any of the anchors noted in Table 5-1 may be satisfactory. For very thin slabs (less than 1 m thick), use of Split-Sets may be the least expensive for temporary anchoring. Use of Swellex or the other anchor systems could also be considered. Swellex anchoring systems may be particularly suitable for slabs up to 3 to 4 m thick. The system allows a large number of anchors to be installed very quickly, although no appreciable corrosion protection is present since the anchor is not grouted. Line Creek personnel have developed a method of utilizing old shovel cable as a grouted dowel (untensioned) anchor. The cable is degreased by sand blasting prior to installation in a grout filled hole. Photograph 5-1 and 5-2 show examples of installations.

5.5.3 Corrosion Protection

The need for corrosion protection for installed anchors should be assessed relative to the anticipated design life of the anchor and the presence of corrosive elements in the groundwater. It is generally considered that the presence of chloride and sulphate ions, or acidic conditions, can result in accelerated rates of steel corrosion. Tilman et al (1984) provide data on calculation of corrosion rates. The most effective corrosion protection is obtained from use of a complete sheath or cover over the anchor to provide 100% protection against the ingress of groundwater. This type of corrosion protection (inherent in the Dywidag double corrosion protective system, for example) is available, but is prohibitively expensive for mining applications, except in special circumstances.

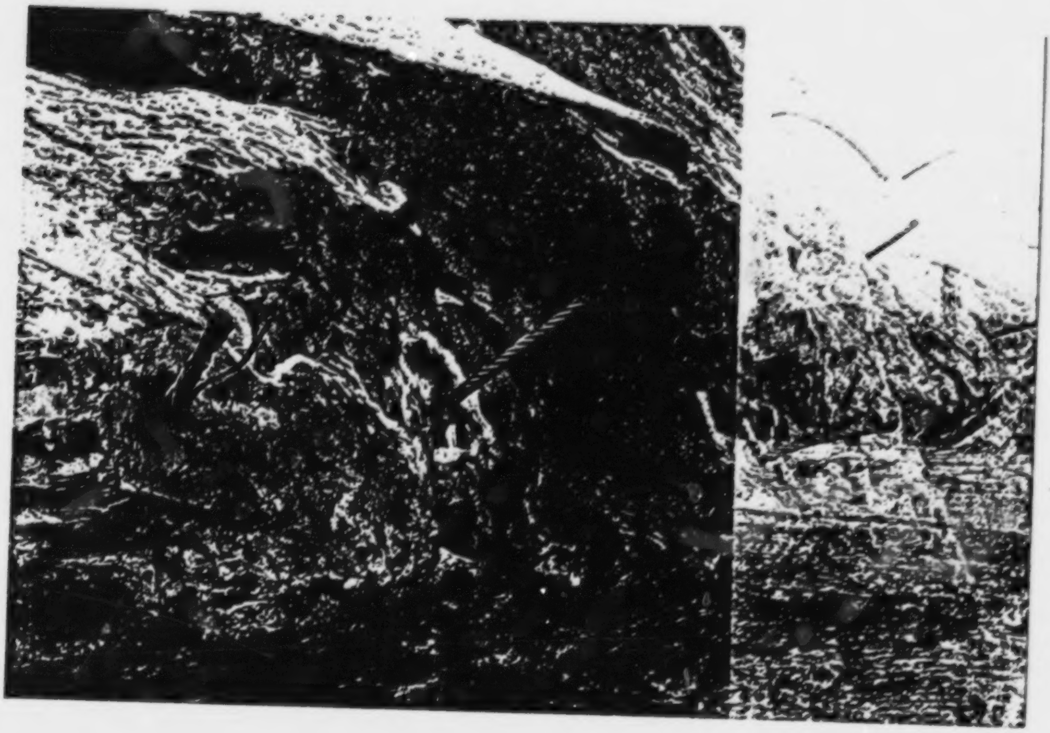


PHOTO 5-1: SHOVEL CABLE USED AS GROUTED DOWEL AT LINE CREEK.

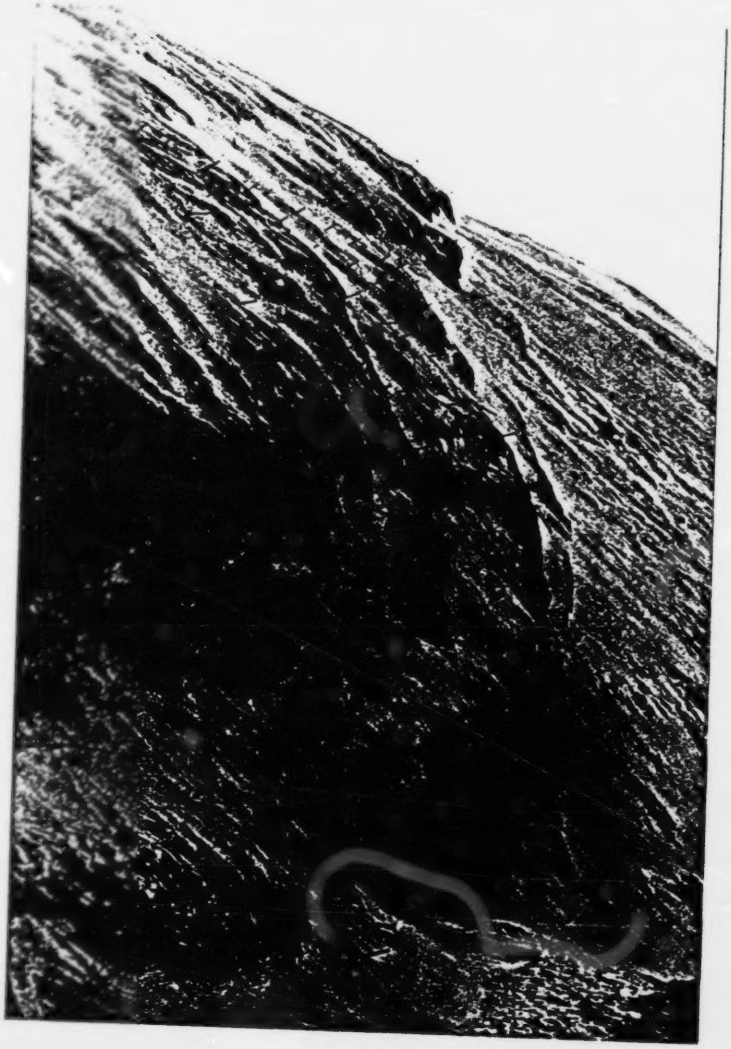


PHOTO 5-2: SHOVEL CABLE USED AS GROUTED DOWEL AT LINE CREEK.

A moderate level of corrosion protection, generally sufficient for periods of at least 5 years, is afforded by a continuous cement grout cover at least 15 mm thick over the bar. The basic environment produced by the grout reduces corrosion considerably. In order to reduce stress cracking of the grout, it may be preferable to prestress the bolts or anchors prior to grouting.

Galvanizing of Split-Sets or Swellex friction rock stabilizers may provide additional corrosion protection, since neither system is used with grout. Tests by Tilman et al (1984) found that the rate of corrosion for rock stabilizers was greatly reduced when they were galvanized. Galvanizing should not be used on bar where cement grout provides the anchorage, since galvanizing reduces the grout/steel bond by approximately 50% (Littlejohn and Bruce (1977). Polyester resin provides mechanical protection against the ingress of groundwater, but is subject to pinholing, and the protection provided may not be continuous.

Corrosion is most likely to occur on unprotected bar anchors or rock stabilizers. Depending upon steel types, stress level and corrosion potential, the working life of an non-corrosion-protected anchor may be in the order of 2 to 5 years. Much lower design lives may occur in aggressive environments, (for example, if pyrite is present).

5.5.4 Orientation

Two factors which affect anchor orientation are:

- Costs of drilling and materials,

- accessibility.

These two factors interact with each other at a particular anchor location to control anchor design. In considering anchor orientation, the following should be noted:

a) Tensioned anchors increase the normal stress on the potential failure plane prior to any movement and tend to resist that initial movement;

b) Untensioned anchors (dowels) have no effect until minor movement occurs, at which time they either self-tension or provide shear strength to resist further movement;

c) Simple mechanics indicates that the optimum angle of an anchor or dowel is at Øe to the potential failure plane angle, measured up-dip, where Øe is the effective angle of shearing resistance along the potential failure plane, incorporating both the effects of basic friction and roughness due to surface asperities;

d) Anchors always act in tension, by virtue of the process of installation; dowels, on the other hand, may act in tension or shear, depending on orientation.

Hence, both anchors and dowels should, ideally, be installed in accordance with (c) above. This would ensure minimum costs in materials. However, access conditions on site can pre-empt this optimum orientation and installation orientations different from the ideal can often be more practical.

Figure 5-4 indicates anchoring methods and usable ranges of orientation for tension and shear.

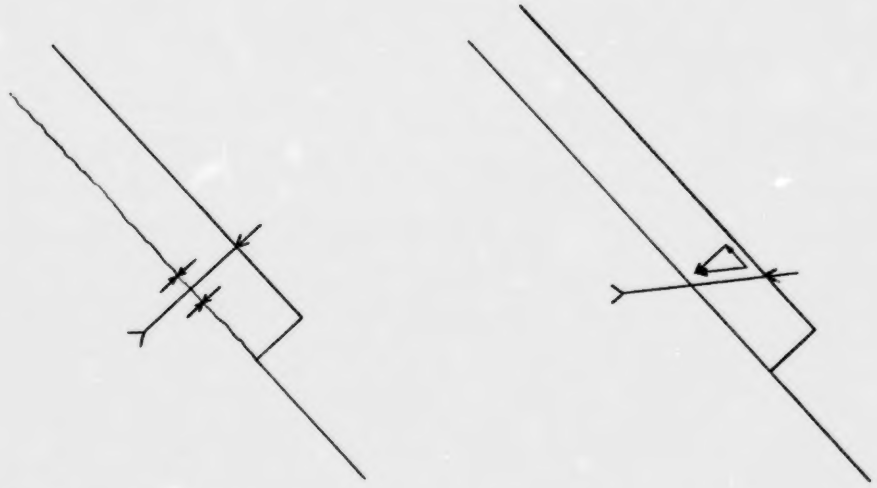
When installing an anchor/dowel to act in tension, the resistance to movement is provided by the tensile strength of the anchor bar and the shear strength of the anchoring medium (mechanical, grout or resin). Since the tensile strength of steel is relatively high, the area of the anchoring medium is the critical factor, and long anchored lengths in large diameter holes provide extremely effective resistance.

When dowels are installed in shear, the resistance to movement is provided essentially by the shear strength of the anchor bar, which is a relatively inefficient way to utilize the strength characteristics of the bar, since the shear strength of steel is a mere fraction of its tensile strength. Hence, dowels in shear tend to be short and either large diameter or numerous in quantity. Problems have occurred with the use of shear dowels since the system is inherently unstable. Any design should carefully consider the shear behaviour of the system.

The ultimate choice between dowels and anchors depends on the tolerance for small scale movement and its implications with respect to drainage and infiltration. The choice between tension and shear depends on accessibility and relative costs.

5.6 BENCHING

Benching is not commonly employed on non-vertical footwalls in Canada, except as a last resort, due to the severe penalty of the extra stripping required. However, on a steep or extremely faulted or folded footwall, benching may be the only alternative to provide stability.



a) Increase of normal stress either due to shearing on rough joint or anchor prestress

b) Component of anchor force resisting movement

MECHANISMS OF ANCHOR ACTION

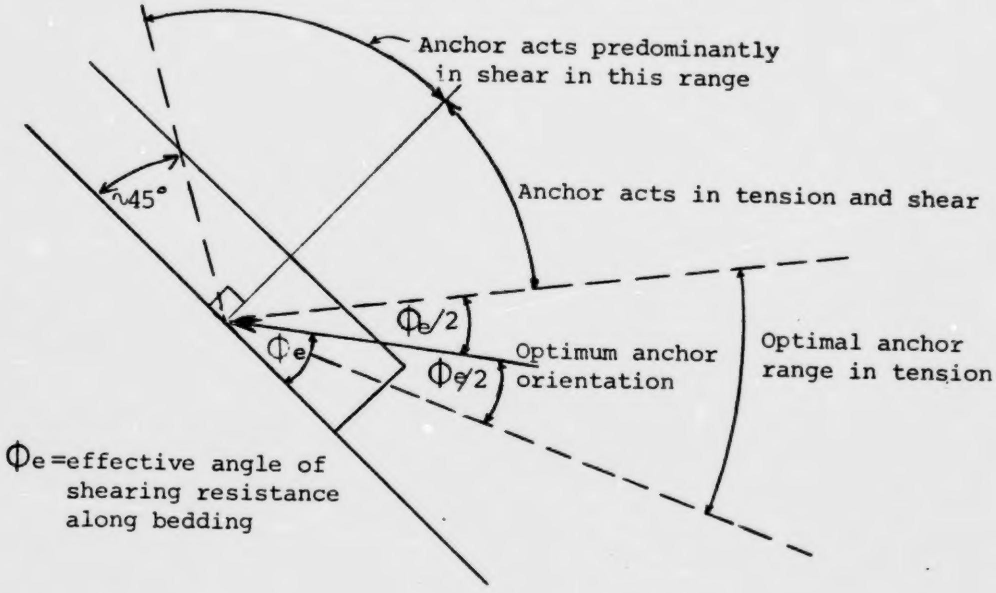

Anchor acts predominantly in shear in this range
Anchor acts in tension and shear
~45°
Φe/2
Φe
Φe/2
Optimum anchor orientation
Optimal anchor range in tension
Φe =effective angle of shearing resistance along bedding

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FIGURE 5-4
ANCHORING METHODS

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The optimal use of benches is to locate them at rolls, so that either or both of the following objectives are satisfied:

a) The axial stress in the slab above the roll is reduced, or

b) the weight of material above a roll acts to produce stability.

Where it is possible to locate benches at the optimum position, the stripping for the benching may be carried down the footwall and the bench put in at the optimum location with respect to wall geometry. Alternatively, where numerous small rolls of limited depth occur throughout the footwall, methods suggested by Corbyn (1977) may be used to limit propagation of failure. Basically, Corbyn's methods consist of reducing the slope angle so that there is sufficient material overlying a small, limited roll to provide a vertical or radial stress sufficient to restrain movement.

When benching is undertaken on a footwall, care should be taken not to undercut bedding. In particular, there may be a tendency to undercut bedding at the back of the bench, where excessive subgrade drilling or toe blasting may cause significant rock damage.

There is frequently a difference in short and long-term stability. That is, a slope may be stable for a short period of time but eventually fail over a longer period of time. This may be due to creep, stress relaxation, changes in pore pressure (especially dissipation of negative pore pressures) and progressive fracturing or progressive strength change.

It should also be noted that strata high upon the footwall may be exposed to weathering as well as the processes above for a number of years, while strata low down on the slope may be exposed for much shorter periods of time. While these various effects are difficult to quantify, they do need to be considered in the design and mining process as well as in the design of anchors and drains.

6.0 CASE HISTORY - LINE CREEK

6.1 INTRODUCTION

Field investigations at Line Creek Mine were designed to determine the geotechnical characteristics of the rock material and rock mass forming the footwall, hydrogeological conditions and their variation during the excavation process, the natural stress regime prevailing at the footwall toe, and footwall movements occurring as a result of the excavation process. Field work comprised drilling and core logging, geophysical borehole logging, structural mapping, the installation and monitoring of piezometers, inclinometers and extensometers, and the determination of in situ stresses. Associated laboratory testing comprised index tests, uniaxial compressive strength determinations, Brazilian (tensile) testing, density measurements, the determination of elastic (Young's) modulus and Poisson's Ratio over the elastic stress range, and the determination of deformation modulus and deformation ratio over the inelastic stress range of interest.

Field work was completed during the period April 14 to May 3, 1986. Drilling was carried out by Drilcor Industries Ltd. of Delta, B.C. Geophysical logging was completed by Crows Nest Resources Ltd. Instrumentation was supplied by Slope Indicator Canada Ltd. (inclinometer casing), R.S. Technical Instruments Ltd. (piezometers and extensometers), and International Mining Services Inc. (stress cells). All field work was carried out under the supervision and direction of Mr. G.J. Baldwin, P. Eng. of Hardy Associates (1978) Ltd. Laboratory testing was completed in the Burnaby, B.C. offices of Hardy Associates (1978) Ltd. on completion of field work. Non-destructive biaxial tests on overcored stress cells were completed by International Mining Services Inc.

This chapter outlines the methodology of the various investigative procedures and the results and conclusions thus derived. While these results and conclusions relate specifically to the footwall at Line Creek Mine, the intention is that these observations and deductions will permit the extrapolation of appropriate investigative procedures and problem solutions to other open pit coal mines in mountainous areas. A plan of the Line Creek Mine, at the time of field work, is presented in Figure 6-1.

6.2 DRILLING AND CORE LOGGING

Diamond core drilling at the Line Creek Mine was completed by Drilcor Industries Ltd. during the period April 14 to May 3, 1986. Four types of diamond core holes were drilled:

1) "S" holes, for in situ stress measurement;
2) "P" holes, for piezometer installation;
3) "I" holes, for inclinometer casing installation; and
4) "E" holes, for extensometer installation.

The objective of this drilling program was to explore the nature of the footwall at representative locations during the mining process. Hence, the holes were concentrated in three locations. Holes 86-S1, 86-E1, 86-P1 and 86-I1 were located at the toe of the footwall where the footwall is reasonably uniform and where excavation at the toe was planned during the early part of the study. Holes 86-P2, 86-E2 and 86-I2 were located approximately 100 m south along the footwall toe, where the footwall is uniform and excavation planned during the latter part of the study. Hole 86-P3 was located approximately 50 m east of 86-P2, perpendicular to the footwall, in the floor of the

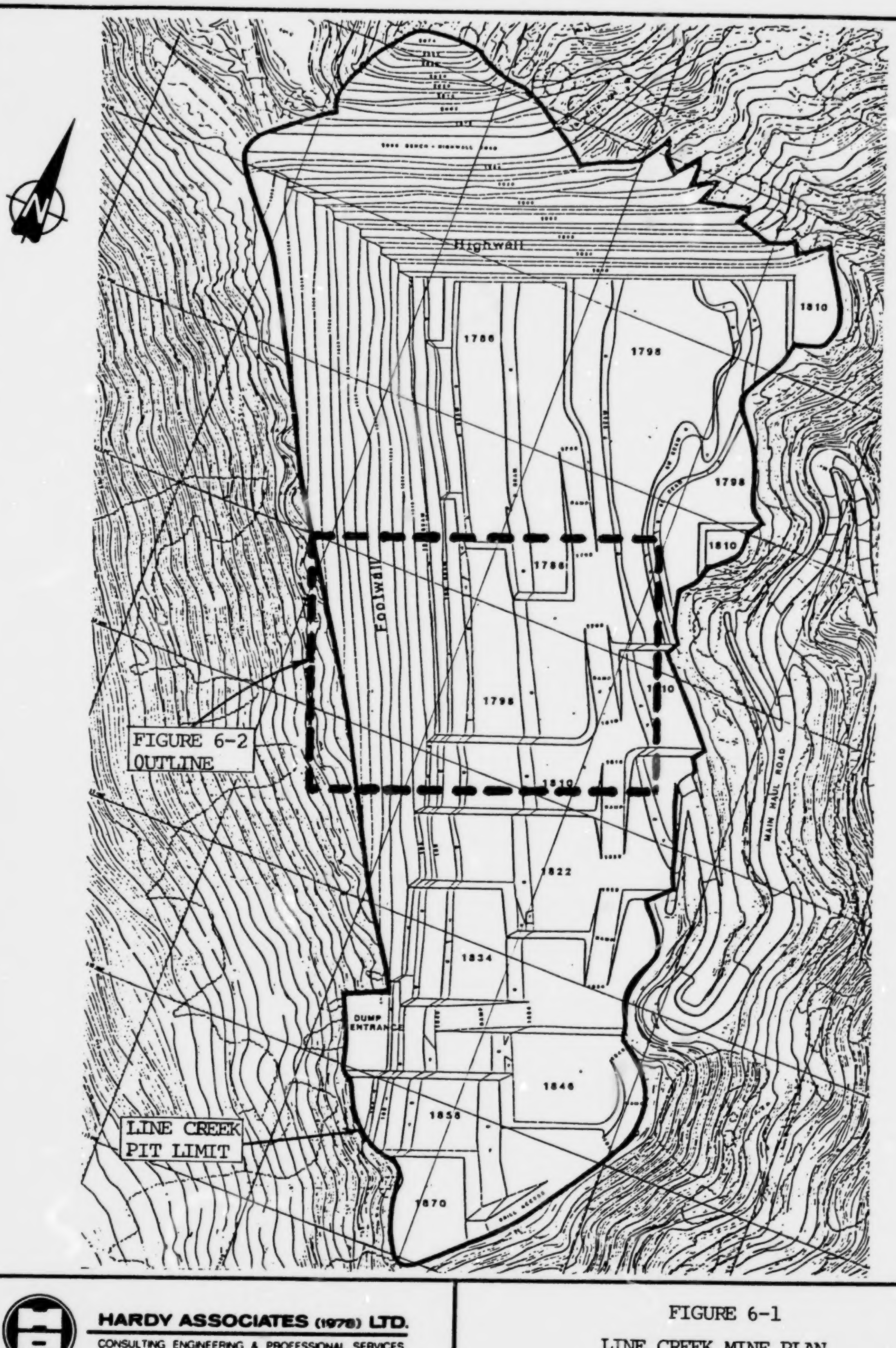
N
Highwall
1810
1786
1798
1798
1810
Footwall
1786
1810
1798
1810
1822
MAIN HAUL ROAD
FIGURE 6-2 OUTLINE
1834
DUMP ENTRANCE
1846
1858
LINE CREEK PIT LIMIT
1870

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FIGURE 6-1
LINE CREEK MINE PLAN

SCALE 1: 6670 | DATE 09/86 | MADE BM | CHKD. GJB | JOB: VG03957 | PLATE

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pit, with the objective of exploring footwall conditions below the pit floor, prior to exposure through the mining process.

Rotary percussion drilling, utilizing a Traxxon track-mounted drill belonging to the mine, was carried out by Line Creek staff during the latter part of April, 1986. These "G" holes were located to investigation lateral variations, if any, in the footwall.

"E" holes, "G" holes and the one "S" hole were drilled perpendicular to the footwall, with inclinations of approximately 45° from the vertical. All remaining holes were vertical. "E" Holes, "P" holes and "I" holes were drilled using a Drilcor-assembled, high-speed rotary drill with a wireline core recovery system. Core bit sizes used were NQ (75.8 mm diameter) and HQ (96.0 mm diameter). Clean water was used as the flushing medium for all cored holes. For the "S" hole, a Winkie drill with a modified water swivel was used. Core bit sizes utilized were 150 mm diameter, diamond-faced for overcoring, and EX (38 mm diameter) diamond-faced for borehole inspection and instrumentation installation.

The "P" holes, "E" holes, "G" holes and "I" holes were sunk to the Lower Sandstone, below the Lower Split. The "S" hole investigated only the Footwall Sandstone.

The locations of the investigation holes and sections are shown in Figure 6-2 (in pocket). All holes were located in consultation with the mine in areas which were accessible at the time of the study and which would optimize information in the time frame available.

Logging of the holes was in two forms:

- geophysical logging,
- geotechnical core logging.

Geophysical logging of all holes (except 86-S1) was carried out by Line Creek personnel using a natural gamma sonde. Though this tool was found to be useful in correlating boreholes, the use of a second sonde, probably a neutron sonde, would be needed to precisely define the sandstone-coal interfaces.

Geotechnical core logging was initiated on site during field work and completed in Hardy Associates laboratories in Burnaby, B.C. The logging process involved the identification of rock type, engineering descriptions of the rock materials and rock masses and percent core recovery. All core was photographed. The borehole logs and photographs, together with a comprehensive explanation of methodology, are presented in Appendix 'D', while the natural gamma logs are presented on cross-sections in Figure 6-3 (in pocket).

6.3 STRUCTURAL MAPPING

Structural data was collected from three sources:

a) Rock core from boreholes,

b) Discontinuity mapping of a section through the footwall at the crest,

c) Discontinuity mapping on the face of the footwall.

Of the boreholes sunk for this study, three were logged in detail (86-I1, 86-I2 and 86-P3). Discontinuity data from these three holes was rotated and plotted on a lower hemisphere, equal angle stereonet. Data from the section and face mapping was added to make a total of 290 discontinuity recorded measurements, including details of orientation, length and roughness. This data was treated statistically to determine major discontinuity sets, their orientations, mean lengths and mean roughnesses.

6.4 INSTRUMENTATION AND IN SITU TESTING

6.4.1 Introduction

A variety of instrumentation was utilized together with in situ testing techniques to determine the geotechnical characteristics of the footwall and its response to mining activity and seasonal changes. The objectives were to measure hydrogeological parameters and their variation, footwall movement and/or relaxation, and the determination of the in situ stress state at the toe of the footwall. The following sections outline the instrumentation methods and testing techniques employed.

6.4.2 Permeability Testing and Piezometers

Following completion of drilling of each cored hole and inspection and preliminary logging of recovered rock core samples, an assessment was made of the hydrogeological characteristics of the various strata, with a view to identifying representative horizons for permeability testing. This assessment was aided by the provision by Crows Nest Resources Ltd. of previous data collected by Golder Associates (1979) in the premining stages of mine exploration. Permeability testing was then conducted in the horizons of interest.

The permeability test procedure involved the use of a double packer system to isolate the section of borehole being tested. Water was then added to this section through a riser pipe under either falling head or constant head conditions. In some instances, where piezometric pressures in the test section were high, the rising head method was used, involving the removal of water from the section. A diagram of the packer system is shown in Figure 2.3 of this report. Hvorslev's method was used to analyze the data to arrive at permeability values for the tested sections.

Based on the results of the permeability testing, piezometers were installed in selected horizons to monitor groundwater pressure variations during the mining process, and to observe seasonal, and other, fluctuations. It was recognized that rapid-response piezometers would be required to record transitory peaks and troughs in groundwater pressure in the relatively low permeability materials. In addition, remote-reading piezometers were preferable, to simplify the monitoring process as the mine was deepened. For these reasons, pneumatic piezometers were selected. The type installed were Petur P-100-1 general purpose pneumatic piezometers manufactured by R.S. Technical Instruments Ltd. of Port Coquitlam, B.C. When installed, the piezometers were surrounded by a clean, coarse, angular gravel (chicken grit) extending over the height of the permeability section under observation in the borehole. Bentonite seals were positioned to isolate the section within the borehole. A diagrammatic representation of the completed installation for each borehole is given in the instrumentation column on the borehole logs in Appendix 'D'. Monitoring of the water pressures registered by the piezometers was carried otu by Hardy Associates (1978) Ltd. and Line Creek staff using a Petur pneumatic piezometer readout box, which gives a direct reading of piezometric pressure at the tip.

6.4.3 Inclinometers

Two inclinometer casings were installed in the "I" holes (Figure 6-2). The objective here was to monitor footwall movement during the mining process. The inclinometer casing was 69.85 mm O.D. C.P.I. plastic casing with Westbay couplings, supplied by Slope Indicator Canada Ltd. of Richmond, B.C. This casing was grouted into the holes, with the grooves aligned parallel and perpendicular to the footwall, to simplify the monitoring analysis. The inclinometer sensor was lowered inside the casing, running on wheels inside the grooves to obtain inclination readings. The readings, displayed on a Digitilt readout unit, were subsequently analyzed and plotted using a computer program to show movement, if any. The sensor and readout unit, manufactured by Slope Indicator Co., Seattle, U.S.A., are owned by Hardy Associates (1978) Ltd. On-site readings were taken by both Hardy Associates and Line Creek personnel, all data being reduced and plotted in Hardy Associates Burnaby offices.

6.4.4 Extensometers

Two extensometers were installed in the "E" holes (Figure 6-2). As with the inclinometers, the objective here was to monitor footwall movement during the mining process. The extensometers were preassembled, based on knowledge of the anticipated geology. Four anchors were specified at 3.5 m. 7.0 m, 10.0 m and 15.0 m from the extensometer head. The 3.5 m and 7.0 m anchors were in the Footwall Sandstone (above the Upper Split), the 10.0 m anchor in the Intermediate Sandstone (between the Upper and Lower Splits), and the 15.0 m anchor in the Lower Sandstone (below the Lower Split). The geology proved to be almost exactly as anticipated, and both extensometers were fully grouted into their respective boreholes. The extensometers were rod extensometers manufactured by R.S. Technical Instruments Ltd. Both extensometers were fitted with remote readout heads for simplicity in monitoring as the mine was deepened. The remote readout heads are read by using a multimeter to read voltage output during excitation by a 12 volt battery. The voltage output is directly proportional to extension (or compression), and is easily converted. Details of the extensometer are given in Appendix 'E'.

6.4.5 In Situ Stress Measurement

Knowledge of the natural stress regime in the footwall slope was considered essential to fully understand the fracture conditions, movements (if any) and potential for failure. Measurement of the in situ stress state within the footwall was carried out using the C.S.I.R.O. Hollow Inclusion Cell. This device was selected in preference to the alternatives (see Section 2.4 and 3.4) because of its history of success, and comprehensive measuring ability. Stress measurements were taken at the toe of the footwall, in the "S" hole, specially drilled for this purpose. Knowledge of the geological conditions prevailing at the site and geometrical considerations suggested that the stress in the Footwall Sandstone (above the Upper Split) was the most important to determine. Hence, stress measurements were concentrated in the central zone of the Footwall Sandstone, between the footwall face and the Upper Split. A comprehensive report on the stress measurement at Line Creek is included in Appendix 'A'.

6.5 LABORATORY TESTING

Non-destructive biaxial testing of large diameter rock core, carried out as part of the in situ stress determination procedure, was carried out by International Mining Services Inc. in their Vancouver laboratories. This is reported fully in Appendix 'A'. All remaining laboratory testing of rock core samples was carried out by Hardy Associates (1978) Ltd. personnel at their Burnaby laboratories.

The testing program included the following:

- Determination of point load index, leading to an assessment of uniaxial compressive strength (71 samples);
- Brazilian (tensile strength) tests (9 samples);
- Uniaxial compressive strength determinations (11 samples);
- Determination of elastic parameters (Young's Modulus and Poisson's Ratio) and non-elastic deformation characteristics (4 samples);
- Bulk density determinations (20 samples).

The objective to these tests was to understand the strength characteristics of the footwall rock materials. Hence, testing concentrated on the Footwall Sandstone.

Elastic parameters and deformation characteristic determinations were determined by the uniaxial loading of cylindrical rock core specimens which had strain gauges attached to them. Each specimen had four electrical strain gauges; two for the measurement of vertical strain, and two for the measurement of horizontal strain. A second sample, also equipped with strain gauges, was used as a "dummy", so that, when the two samples are connected to opposite sides of a Wheatstone Bridge circuit, environmental effects in the test procedure are cancelled.

6.6 RESULTS AND CONCLUSIONS

6.6.1 Introduction

Results of this study have been useful to Line Creek. The ability to monitor slope movements and to analyze the curved slope should be useful in the future as mining uncovers more of the curved footwall slab.

The Line Creek Mine footwall dips at approximately 45° and is currently in the order of 120 m high. Full exploitation of the available coal reserves will necessitate a considerable increase in footwall height, and the investigations carried out as part of this study have enabled an assessment of ongoing footwall stability to be formulated.

The footwall is comprised of massive sandstone, known as the Basal Sandstone, a sequence in the Kootenay Formation, which is understood to be of Upper Jurassic or Lower Cretaceous age. This Basal Sandstone forms the lower boundary of minable coal at Line Creek, and forms a north/south trending syncline, in keeping with the structural style of the southeastern B.C. coal fields. This field investigation has concentrated on the Basal Sandstone forming the footwall, and for clarification purposes in this report, the Basal Sandstone has been subdivided into the following elements:

- Footwall Sandstone - forming the footwall, approximately 9 m thick.

- Upper Split - shaley coal seam, approximately 0.5 m thick.

- Intermediate Sandstone - between splits, approximately 4.5 m thick.

- Lower Split - shaley coal seam, approximately 0.5 m thick.

- Lower Sandstone - below splits.

This strata sequence is shown in Figure 6-3.

The following sections of this chapter outline results and conclusions derived from the investigation, considering the following aspects:

- Rock material quality - intact rock strength and density.

- Rock mass quality - discontinuity data assessment and its impact on geotechnical characteristics.

- Hydrogeological conditions - location of aquifers, aquicludes or aquitards, and groundwater pressure variations.

- Footwall movement - interpretation of inclinometer and extensometer data.

- In situ stress conditions - interpretation of in situ stress state and its impact on mining.

- The stability of the footwall.

Comprehensive logs of all boreholes are included in Appendix 'D'. These logs include data on rock material and rock mass, point load index test results and instrumentation. Photographs of rock core are also included.

6.6.2 Rock Material

An assessment of rock material properties can be made from a review of the test results. These are presented in Tables 6-1 through 6-4, and Figures 6-4 through 6-7.

The Footwall Sandstone is a brown, medium grained, fresh, very strong rock, with the following mean property values:

Bulk Density	2.55 Mg/m^3
Uniaxial Compressive Strength	205.1 MPa
Tensile Strength	9.4 MPa
Elastic (Young's) Modulus	31.8 GPa
Poisson's Ratio	0.13
Deformation Modulus	18.7 GPa
Deformation Ratio	0.02

It may be noted that the mean correlated uniaxial compressive strength derived from the point load index (Table 6-2) for the Footwall Sandstone is significantly less than that value measured directly. This is thought to be due to the anisotropic testing conditions in the point load test. Hence, Table 6-2 should be used primarily as a comparison of strength ranges rather than the determination of absolute values.

TABLE 6-1: POINT LOAD INDEX TEST RESULTS

HOLE NO.	DEPTH (m)	FAILURE LOAD (kN)	PLATEN SEPARATION (mm)	Is (MPa)	Is(50) (MPa)	COMPRESSIVE STRENGTH (MPa)	COMMENTS
86-S1	3.7-4.0	8.61	26	12.74	7.5	141.0	Approximately perpendicular to bedding.
	"	10.59	33	9.72	7.3	144.5	
	"	9.93	31	10.33	7.2	139.0	
	"	11.25	35	9.18	7.2	145.1	
	"	10.59	36	8.17	6.5	131.8	
86-P1	0.4	8.62	45	4.26	3.9	87.4	Perpendicular to bedding, litharenite.
	2.5	8.95	45	4.42	4.0	89.6	" " " core axis, ".
	4.0	9.29	45	4.59	4.2	94.1	" " " core axis, ".
	6.5	8.29	45	4.09	3.8	85.1	
	7.5	8.95	45	4.42	4.0	89.6	
	9.0	5.97	45	2.95	2.6	58.2	Parallel to bedding.
		8.62	45	4.26	3.9	87.4	Perpendicular to bedding.
	10.5	8.62	45	4.26	3.9	87.4	Parallel to bedding.
		10.61	41	6.31	5.5	123.2	Perpendicular to bedding.
	12.0	10.28	45	5.08	4.8	107.5	Litharenite.
	13.3	4.64	38	3.22	2.5	56.0	Perp. to bedding, mudstone.
		2.65	45	1.31	1.2	28.0	Parallel to bedding, mudstone.
	14.8	7.96	45	3.93	3.8	85.1	Litharenite.
	17.6	8.95	45	4.42	4.0	89.6	" "
	18.9	8.29	45	4.09	3.8	85.1	" "
	20.1	1.33	45	0.66	0.6	13.4	Parallel to bedding, coal.
	20.4	2.65	35	2.17	1.7	39.2	Perp. to bedding, coal.
	22.1	5.64	45	2.78	2.5	56.0	
	23.2	9.29	45	4.59	4.2	94.1	
	24.2	9.29	45	4.59	4.2	94.1	

TABLE 6-1 CONT'D: POINT LOAD INDEX TEST RESULTS

HOLE NO.	DEPTH (m)	FAILURE LOAD (kN)	PLATEN SEPARATION (mm)	Is (MPa)	Is(50) (MPa)	COMPRESSIVE STRENGTH (MPa)	COMMENTS
86-E1	1.4	9.29	45	4.59	4.2	94.1	
	5.6	9.95	45	4.91	4.6	103.0	
	10.4	7.96	34	6.89	5.5	123.2	
	12.3	4.64	37	3.38	2.9	59.5	Perp. to bedding, mudstone.
	13.8	1.33	31	1.37	1.1	21.3	Coal.
86-I1	4.0	9.93	45	4.90	4.7	103.4	Sstn.
	7.0	10.54	45	5.23	5.0	110.0	Conglomerate.
	10.5	8.94	45	4.41	4.1	90.2	Sstn. parallel to bedding.
		10.54	35	8.64	6.9	139.4	Sstn. perp. to bedding.
	17.0	9.27	45	4.58	4.2	92.4	Sstn. parallel to bedding.
	22.0	9.27	43	5.01	4.7	101.5	Brown Sstn. parallel to bedding.
	22.6	7.28	45	3.60	3.4	74.8	Brown Sstn. perp. to bedding.
86-P2	1.2	9.95	45	4.91	4.6	103.0	
	3.9	9.62	45	4.75	4.5	100.8	
	6.9	11.28	45	5.57	5.3	118.7	Conglomerate.
	7.4	5.31	45	2.62	2.5	56.0	
	10.3	9.29	45	4.59	4.2	94.1	
	12.9	4.31	38	2.99	2.5	56.0	Perp. to bedding, mudstone.
		2.65	45	1.31	1.2	28.0	Parallel to bedding, mudstone.
	15.9	8.95	45	4.42	4.0	89.6	
	18.8	2.65	33	2.44	1.8	40.3	
	21.0	9.95	42	5.64	4.8	108.6	
	25.3	8.95	45	4.42	4.0	89.6	

TABLE 6-1 CONT'D: POINT LOAD INDEX TEST RESULTS

HOLE NO.	DEPTH (m)	FAILURE LOAD (kN)	PLATEN SEPARATION (mm)	Is (MPa)	Is(50) (MPa)	COMPRESSIVE STRENGTH (MPa)	COMMENTS
86-E2	1.4	7.96	45	3.93	3.8	85.1	Parallel to bedding.
		11.28	46	5.33	4.9	109.8	Perpendicular to bedding.
	2.8	8.62	45	4.26	3.9	87.4	
	4.3	12.60	42	7.14	6.3	141.1	
	4.8	10.61	39	6.98	6.0	134.4	
	7.1	9.29	41	5.52	5.0	112.0	Perpendicular to bedding.
	7.4	5.31	45	2.62	2.5	56.0	Parallel to bedding.
	10.2	11.28	45	5.57	5.2	116.5	
	11.6	7.96	45	3.93	3.8	85.1	
	13.9	1.33	43	0.72	0.7	15.2	Mudstone.
86-I2	2.8	15.89	56	5.07	5.6	134.4	Sstn.
	7.1	15.22	57	4.68	5.0	120.0	Qtz. chert conglomerate.
	21.1	8.61	54	2.95	3.2	75.5	Bedded, brown arkose.
	24.2	17.87	45	8.82	8.1	178.2	Perp. to bedding, Sstn.
	19.2	2.98	58	0.89	0.9	23.3	Parallel to bedding, mudstone.
86-P3	47.6	8.62	45	4.26	3.9	87.4	
	49.6	9.45	45	4.67	4.3	96.3	
	51.0	8.95	45	4.42	4.0	89.6	
	52.2	9.27	45	4.58	4.3	94.6	
	54.0	7.94	45	3.92	3.8	83.6	
	55.5	10.59	45	5.23	5.1	112.2	
	57.1	9.76	46	4.61	4.4	96.8	
	53.9	9.27	44	4.79	4.7	102.5	Parallel to bedding, conglomerate.

TABLE 6-2: MEAN UNIAXIAL COMPRESSIVE STRENGTH DERIVED FROM POINT LOAD INDEX FOR EACH BOREHOLE AND ROCK FORMATION

HOLE NO.	MEAN UNIAXIAL COMPRESSIVE STRENGTH (MPa) DERIVED FROM POINT LOAD INDEX				
	FOOTWALL SANDSTONE	UPPER SPLIT	INTERMEDIATE SANDSTONE	LOWER SPLIT	LOWER SANDSTONE
86-S1	140.3	-	-	-	-
86-P1	90.9	42.0	86.6	26.3	81.4
86-E1	98.5	-	123.2	40.4	-
86-I1	110.7	-	92.4	-	88.1
86-P2	94.5	42.0	64.9	-	99.1
86-E2	103.7	-	100.8	15.2	-
86-I2	127.2	-	-	23.3	126.8
86-P3	95.4	-	-	-	-
MEAN	103.9	42.0	89.7	28.6	96.9
STANDARD DEVIATION	23.3	16.2	23.3	17.7	34.4
RANGE	56.0-145.1	28.0-56.0	40.3-123.2	13.4-59.5	56.0-178.2
NO. OF RESULTS	43	4	9	6	9

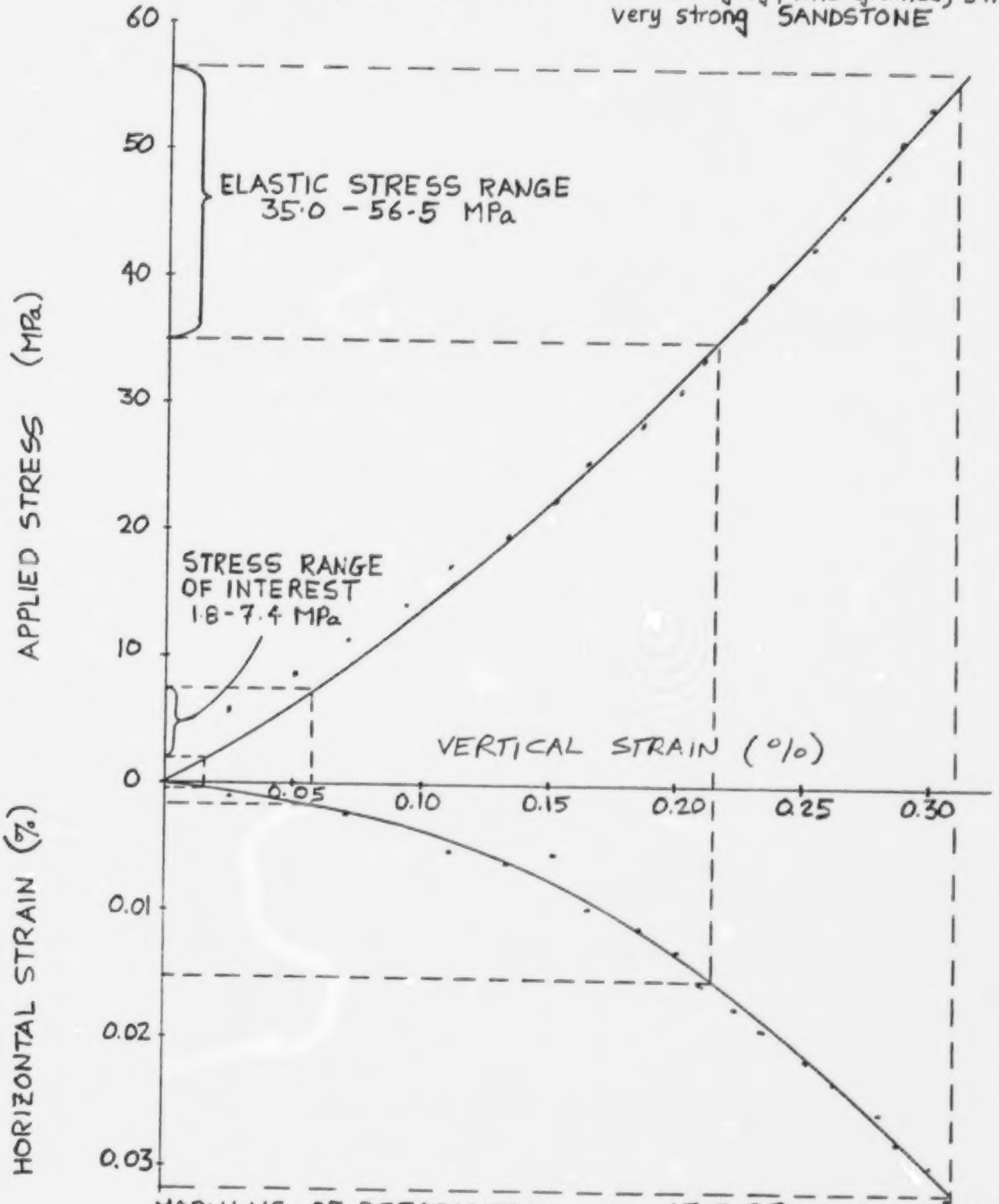
TABLE 6-3: SUMMARY OF UNIAXIAL COMPRESSIVE STRENGTH AND DEFORMATION TESTING ON FOOTWALL SANDSTONE SAMPLES

HOLE NO.	DEPTH (m)	DENSITY (Mg/m^3)	UNIAXIAL COMPRESSIVE STRENGTH (MPa)	STRESS RANGE OF INTEREST 1.8 - 7.4 MPa		ELASTIC STRESS RANGE > 16.9 - 39.5 MPa	
				DEFORMATION MODULUS (GPa)	DEFORMATION RATIO	ELASTIC MODULUS (GPa)	POISSON'S RATIO
86-P1	6.0	2.59	201.9	25.6		31.2	
86-E1	3.0	2.58	210.2	13.5	0.03	22.6	0.17
	4.8	2.60	263.0	21.7		33.6	
	6.0	2.59	223.2	16.5	0.02	29.8	0.10
	11.0	2.59	168.3	17.6		29.5	
86-P2	6.0	2.60	231.9	23.3		35.7	
86-E2	3.0	2.57	176.6	12.2	0.02	29.3	0.08
	4.8	2.61	223.2	21.8		35.1	
	6.0	2.52	193.1	13.0	0.02	38.1	0.17
	11.0	2.56	190.0	21.7		31.6	
86-P3	54.4	2.54	174.9	18.8		33.1	
MEAN VALUES		2.58	205.1	18.7	0.0225	31.8	0.13
STANDARD DEVIATION		0.03	28.7	4.5	0.01	4.1	0.05

TABLE 6-4: SUMMARY OF BRAZILIAN TEST RESULTS ON FOOTWALL SANDSTONE SAMPLES

HOLE NO.	DEPTH (m)	DENSITY (Mg/m^3)	TENSILE STRENGTH (MPa)	COMMENTS
86-E1	2.8	2.51	7.83	90° to Lineations.
	6.2	2.52	7.29	90° to Lineations.
86-E2	3.2	2.57	11.61	90° to Lineations.
	6.2	2.45	5.86	90° to Lineations.
86-P1	5.8	2.53	9.34	45° to Lineations.
	10.8	2.51	13.06	70° to Lineations.
86-P2	5.8	2.51	12.27	45° to Lineations.
	10.8	2.57	9.27	45° to Lineations.
86-P3	54.6	2.51	7.89	45° to Lineations.
MEAN VALUE		2.52	9.38	
STANDARD DEVIATION		0.04	2.46	
RANGE		2.45 - 2.57	5.86 - 13.06	

BOREHOLE	86 - E1
SAMPLE DEPTH	3.0 m
SAMPLE DESCRIPTION	Medium grey, fine-grained, strong to very strong SANDSTONE



MODULUS OF DEFORMATION = 13.5 GPa
DEFORMATION RATIO = 0.03
} STRESS RANGE 1.8 - 7.4 MPa

MODULUS OF ELASTICITY = 22.6 GPa
POISSON'S RATIO = 0.17
} STRESS RANGE 35.0 - 56.5 MPa

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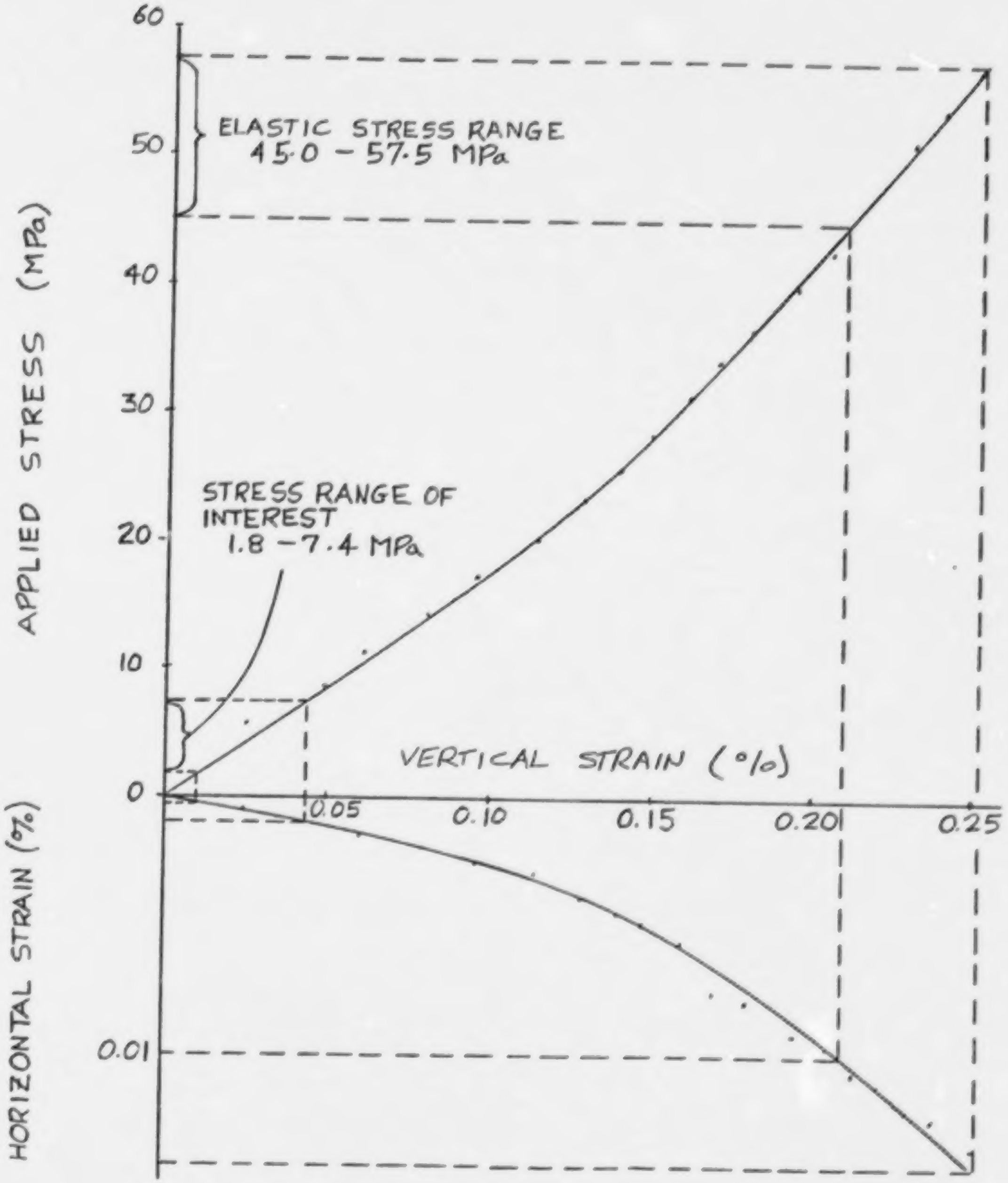
FIGURE 6-4
LABORATORY ROCK DEFORMATION
TEST RESULTS

SCALE AS SHOWN	DATE 1? FEB	MADE H.G.	CHKD. G.J.B.	JOB: VG03957	PLATE

BOREHOLE 86-E1
SAMPLE DEPTH 6.1 m
SAMPLE DESCRIPTION Medium grey, fine-grained, strong to very strong SANDSTONE



MODULUS OF DEFORMATION = 16.5 GPa
DEFORMATION RATIO = 0.02
STRESS RANGE 1.8 - 7.4 MPa

MODULUS OF ELASTICITY = 29.8 GPa
POISSON'S RATIO = 0.10
STRESS RANGE 45.0 - 57.5 MPa

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FIGURE 6-5
LABORATORY ROCK DEFORMATION
TEST RESULTS

SCALE AS SHOWN	DATE 11/86	MADE M.G	CHKD. G.I.B.	JOB: VG03957	PLATE

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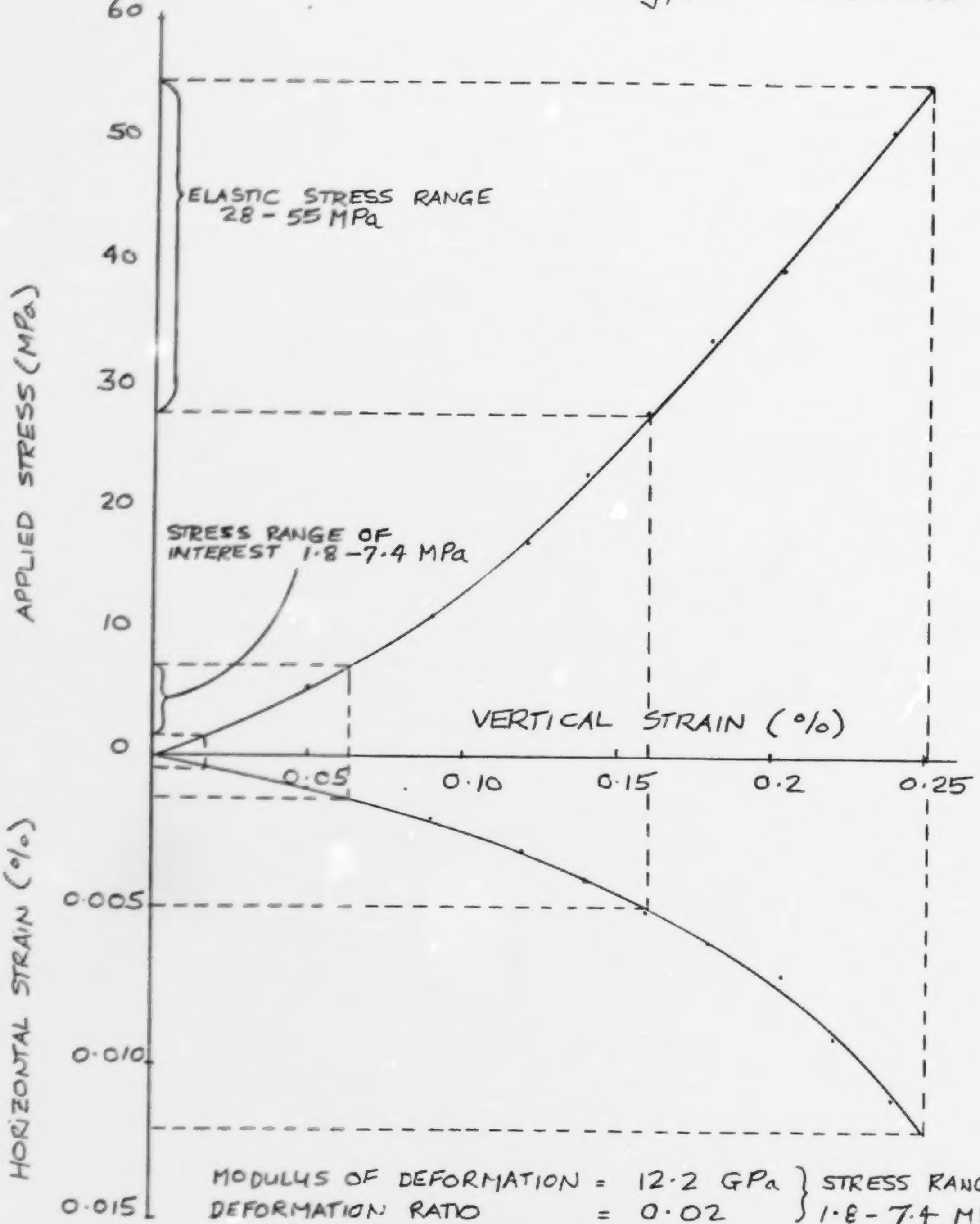
BOREHOLE	86-EZ
SAMPLE DEPTH	3-0m.
SAMPLE DESCRIPTION	Light to medium grey, fine-grained strong, fresh SANDSTONE



MODULUS OF DEFORMATION = 12·2 GPa } STRESS RANGE
DEFORMATION RATIO = 0·02 } 1·8 - 7·4 MPa
MODULUS OF ELASTICITY = 29·3 GPa } STRESS RANGE
POISSON'S RATIO = 0·08 } 28 -55 MPa

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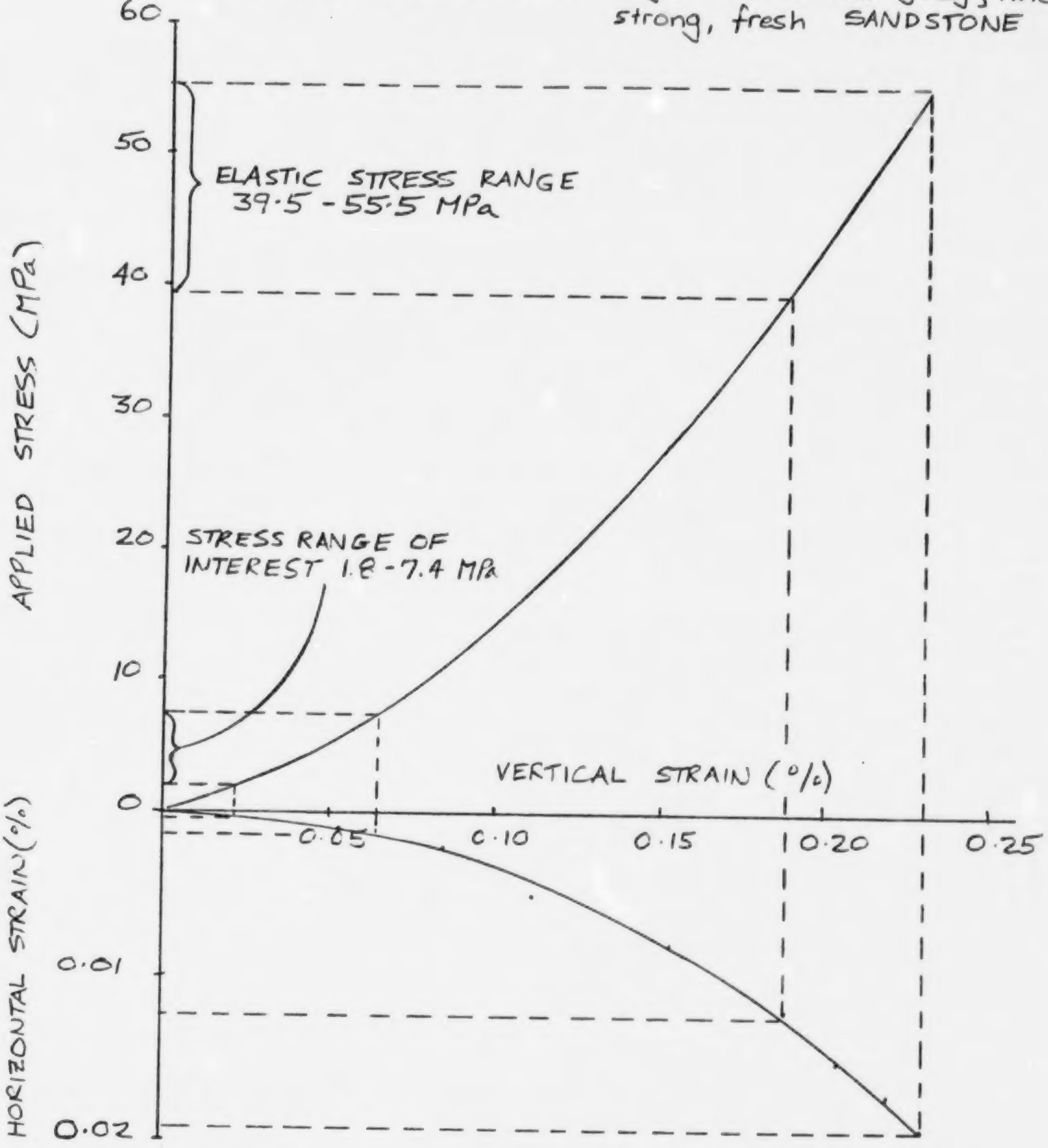
FIGURE 6-6
LABORATORY ROCK DEFORMATION
TEST RESULTS

SCALE AS SHOWN | DATE 10/86 | MADE MG | CHKD. GJB | JOB: VG03957 | PLATE ______

BOREHOLE	86-EZ
SAMPLE DEPTH	6·0 m
SAMPLE DESCRIPTION	Light to medium grey, fine-grained, strong, fresh SANDSTONE



MODULUS OF DEFORMATION	13·0 GPa	STRESS RANGE 1·8 - 7·4 MPa
DEFORMATION RATIO	0·02	
MODULUS OF ELASTICITY	38·1 GPa	STRESS RANGE 39·5 - 55·5 MPa
POISSON'S RATIO	0·17	

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FIGURE 6-7
LABORATORY ROCK DEFORMATION
TEST RESULTS

SCALE AS SHOWN | DATE 11/88 | MADE MG | CHKD. GJB | JOB: VG0 3957 | PLATE

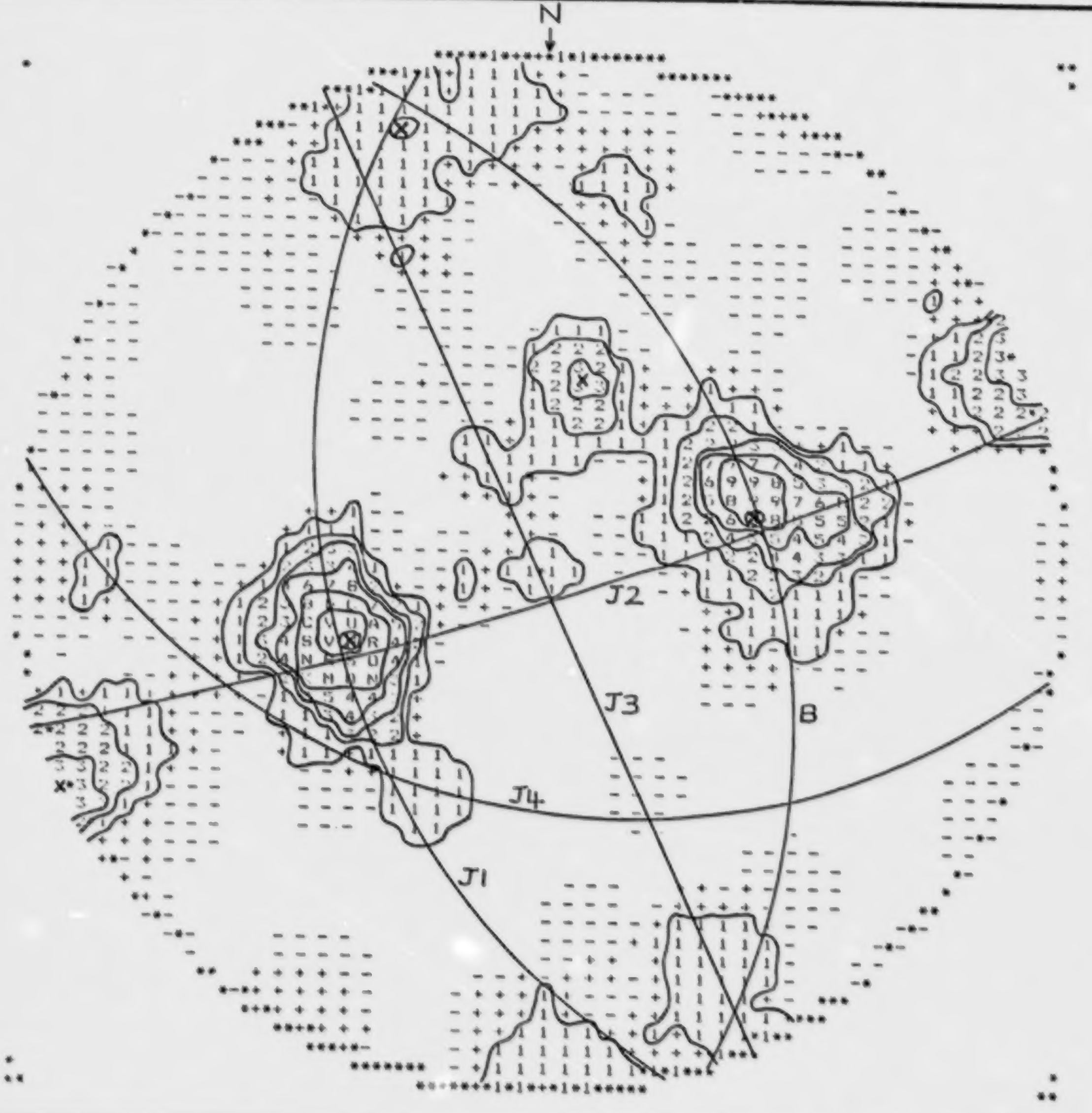
The Upper Split comprises dark grey to black, fine grained, fresh, very weak to moderately strong, shaley, coal or carbonaceous mudstone. It was only possible to test the more intact core pieces, a fact in itself indicative of the variable strength of this horizon. It should be considered a weak horizon, with a correspondingly low unconfined compressive strength.

The Intermediate Sandstone is similar to the Footwall Sandstone, but is more grey in colour, and of slightly lower strength (Table 6-2). The Lower Split is similar to the Upper Split - a weak horizon. The Lower Sandstone is also similar to the Footwall Sandstone, but of slightly lower strength.

From the test results, it will be noted that most attention has been paid to the Footwall Sandstone. This is because it is this sequence which is critical to the stability of the footwall as a whole.

6.6.3 Rock Mass

With the exception of the Upper and Lower Splits, which are essentially cleaved and broken carbonaceous mudstones, the rock mass is massive, with two clearly defined orthogonal joint sets perpendicular to bedding. All discontinuity data from borehole logs and mapping was collected onto one steronet, presented in Figure 6-8. Contouring of this data has resulted in the determination of the following mean joint set orientations:



DIP DIRECTION / DIP OF MAJOR DISCONTINUITIES

BEDDING B	071/43
JOINT SET J1	257/45
JOINT SET J2	163/84
JOINT SET J3	065/90
JOINT SET J4	192/41

SYMBOLS ON STEREONET MEAN

SYMBOL	PERCENT RANGE	
	0 OR LESS	
-	0	1/2
+	1/2	1
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	7
7	7	8
8	8	9
9	9	10
A	10	11
B	11	12
C	12	13
D	13	14
E	14	15
F	15	16
G	16	17
H	17	18
I	18	19
J	19	20
K	20	21
L	21	22
M	22	23
N	23	24
O	24	25
P	25	26
Q	26	27
R	27	28
S	28	29
T	29	30
U	30	31
V	31	32
W	32	33
X	33	34
Y	34	35
Z	35 AND GREATER	

NOTES:

1. Lower hemisphere, equal angle, polar plot
2. 290 observations (all data)
3. Sandstone

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FIGURE 6-8
STEREOGRAPHIC PRESENTATION OF MAJOR DISCONTINUITIES IN THE LINE CREEK FOOTWALL

STRUCTURE	SYMBOL	DIP DIRECTION (degrees)	DIP (degrees)	CONCENTRATION (%)	COMMENTS
Bedding	B	071	43	33	Orthogonal
Joint Set	J1	257	45	11	
" "	J2	163	84	3	
" "	J3	065	90	4	
" "	J4	192	41	4	

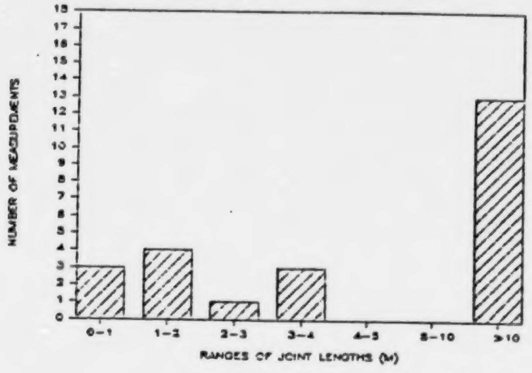
Sampling bias due to borehole orientation is considered responsible for the relatively low concentration of J2 joints.

In addition to orientation, statistical analyses have been completed on discontinuity length and roughness data for the main discontinuity sets. The results of these analyses are presented in Figures 6-9 and 6-10. From these figures, the following mean lengths are roughnesses are assessed:

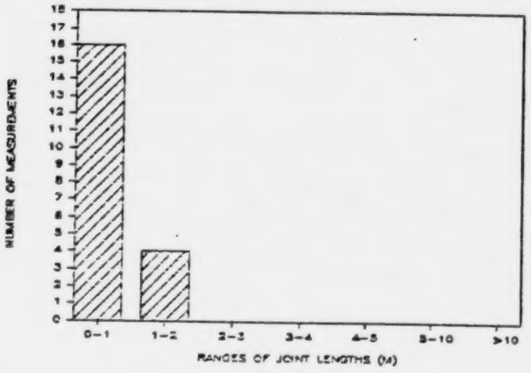
STRUCTURE	SYMBOL	MEAN LENGTH (m)	MEAN ROUGHNESS (degrees)
Bedding	B	> 10	15
Joint Set	J1	1	15
Joint Set	J2	1	15

From the above structural data, there is no evidence of adverse cross jointing, or jointing likely to precipitate plowing failure. Joints J1 and J3 could act as back-release surfaces for plane fail-

BEDDING JOINT LENGTHS



JOINT LENGTHS J1



JOINT LENGTHS J2

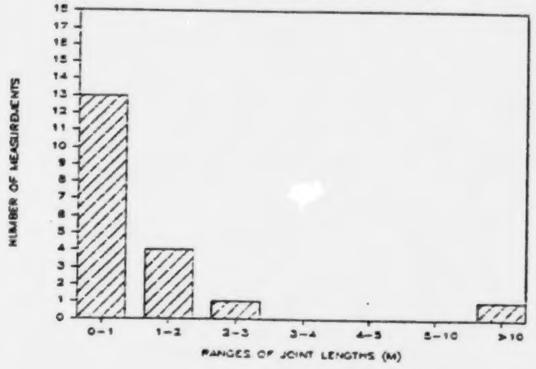


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FIGURE 6-9
STATISTICAL REPRESENTATION OF BEDDING AND MAJOR JOINT LENGTH DATA

SCALE ______ DATE 09/86 MADE ______ CHKD. GJB JOB: VG03957 PLATE ______

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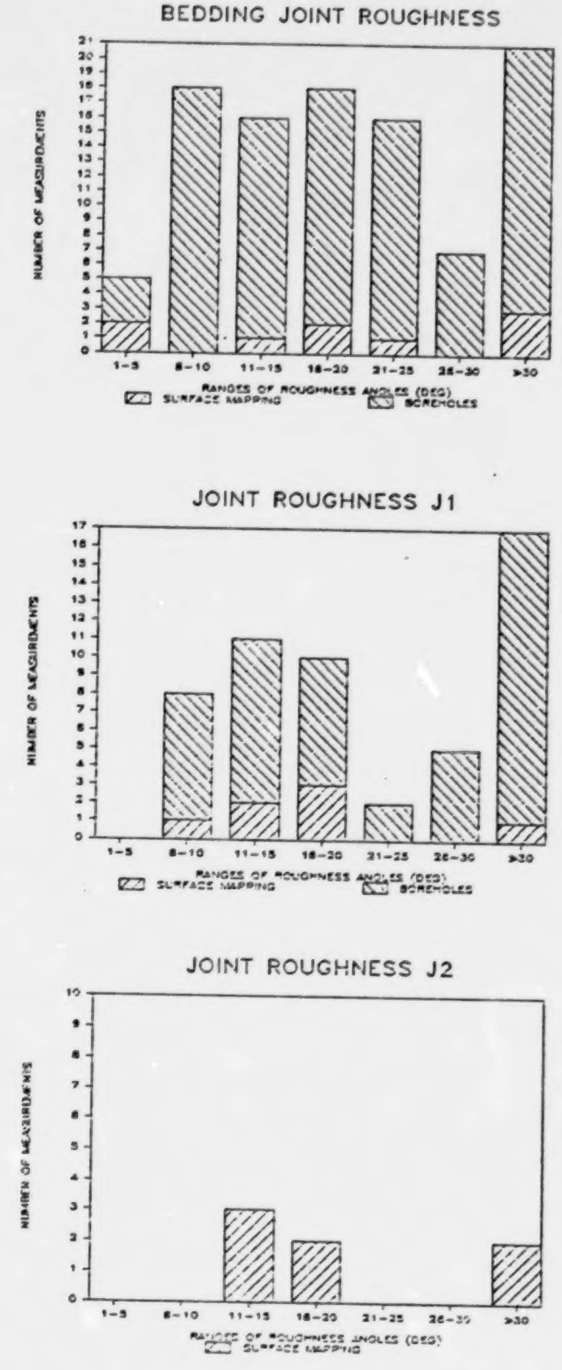

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FIGURE 6-10
STATISTICAL REPRESENTATION OF BEDDING AND MAJOR JOINT ROUGHNESS DATA

SCALE	**DATE** 09/86	**MADE**	**CHKD.** G.I.B	**JOB:** VG03957	**PLATE**

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ures, while joints J2 and J4 could act as side-release surfaces. A failure plane could develop along bedding, B, associated with the above mentioned release surfaces, particularly if the bedding is daylighted or buckling occurs.

Based on an assessed basic friction angle for sandstone of 25 to 35°, and the determined mean joint roughness of 15°, a reasonable value for the angle of shearing resistance, to be used in analysis, is considered to be 40°.

6.6.4 Hydrogeological Conditions

Strata permeability was investigated by carrying out falling, rising or constant pressure head tests using a double packer system. Test intervals were 3.28 m and 6.33 m (see Figures 2-3 and 2-4), and positioned to concentrate on particular geological horizons, with special attention being paid to the Footwall Sandstone and fractured sequences. The results of this in situ testing are presented in Table 6-5.

Extreme variability in permeability was encountered in the Footwall Sandstone, indicating that fracture state is the controlling factor in the movement of groundwater through this rock mass. The results given in Table 6-5 have been assessed in conjunction with those test results obtained by Golder Associates (1979) in the same sequences in order to provide sufficient data for statistical treatment. While the results from the present study and those from Golder Associates are of the same order of magnitude, the present study results are considerably more localized and geologically defined. The net results of this permeability investigation are summarized in Table 6-6, and are based on all available pertinent data. From this table, it can be seen that the Footwall Sandstone appears to be two

TABLE 6-5: SUMMARY OF PERMEABILITY TEST RESULTS - LINE CREEK

BOREHOLE NO.	DEPTH INTERVAL (m)	GEOLOGY	TEST TYPE	TIME LAG (sec.)	PERMEABILITY, K (m./s. X 10^{-9})
86-P1	6.11- 9.39	F. Sstn.	Falling	-	Negligible
	10.91-14.19	U. Split	Rising & Falling	21,600	4.89
	18.39-21.67	L. Split	Falling	12,600	8.70
86-P2	3.57- 9.90	F. Sstn.	Pressure	-	5530.0
	10.52-13.80	U. Split	Rising	2,952	37.2
	17.02-20.30	L. Split	Rising	6,840	16.0
86-P3	51.67-58.00	F. Sstn.	Falling	1,260	57.3
	58.00-61.28	U. Split	Falling	810	140.0
	63.72-67.00	L. Split	Falling	15,120	7.25

TABLE 6-6: SUMMARY OF ASSUMED PERMEABILITY VALUES FOR FOOTWALL STRATA - LINE CREEK

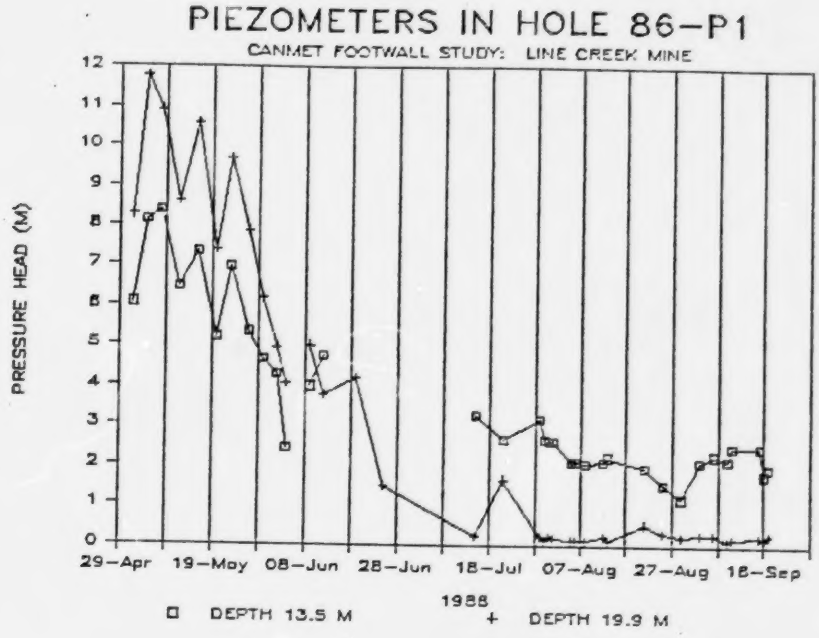
FOOTWALL STRATA	ASSUMED PERMEABILITY VALUE (K X 10^{-8} m./s.)		COMMENTS
	MEAN	STANDARD DEVIATION	
Footwall Sandstone	139.10	216.60	Low Permeability
Upper Split	6.07	7.05	Very Low Permeability
Lower Split	1.06	4.69	
Lower Sandstone	7.00	2.83	

orders of magnitude more permeable than the strata below. This could be due to the opening of fractures in the Footwall Sandstone caused by stress relief following excavation. The permeability values are low, implying that drainage measures would not be expected to intercept large flows of groundwater. However, as stated in Section 3.5, only small volumes of water are needed to generate high internal pressures in rock masses. The extreme variation in results is indicated by the high values for standard deviation presented in Table 6-6.

Details of piezometer installations and depths are given in the borehole logs in Appendix 'D'. The results of piezometric pressure monitoring since installation and daily precipitation data are presented in Figures 6-11a, 6-11b and 6-11c. An inferred piezometric surface for May, 1986, is presented on Section C-C in Figure 6-3. Piezometric pressures have generally declined through the monitoring period, which may be attributed to the arrival of summer weather. It would be very interesting to monitor pressures through the annual cycle to confirm this view.

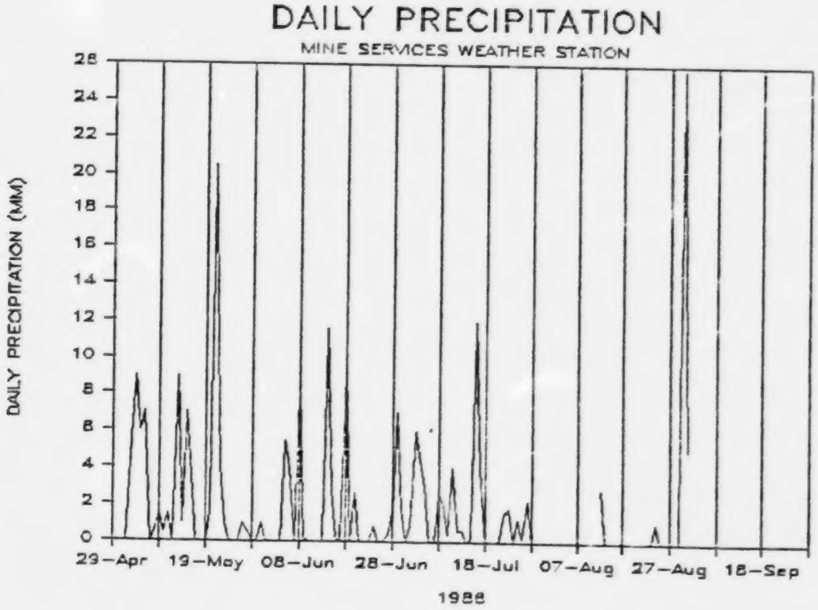
From an examination of the piezometric data from Hole 86-P1, response to rainfall events during May appear to be very rapid, the response becoming less pronounced into the summer. A high rainfall event at the end of August had no apparent effect on the deep piezometer, which appears to be more affected by seasonal variations.

Mildly artesian conditions, indicated by the shallow piezometer in Hole 86-P2, subsided with the onset of summer. The piezometers indicate conditions such as those given in Figure 2-5.



PIEZOMETERS IN HOLE 86-P1

CANMET FOOTWALL STUDY: LINE CREEK MINE



DAILY PRECIPITATION

MINE SERVICES WEATHER STATION

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FIGURE 6-11a
RESULTS OF PIEZOMETRIC PRESSURE
MONITORING - HOLE 86-P1

SCALE	DATE 09/86	MADE	CHKD. GJB	JOB: VG03957	PLATE

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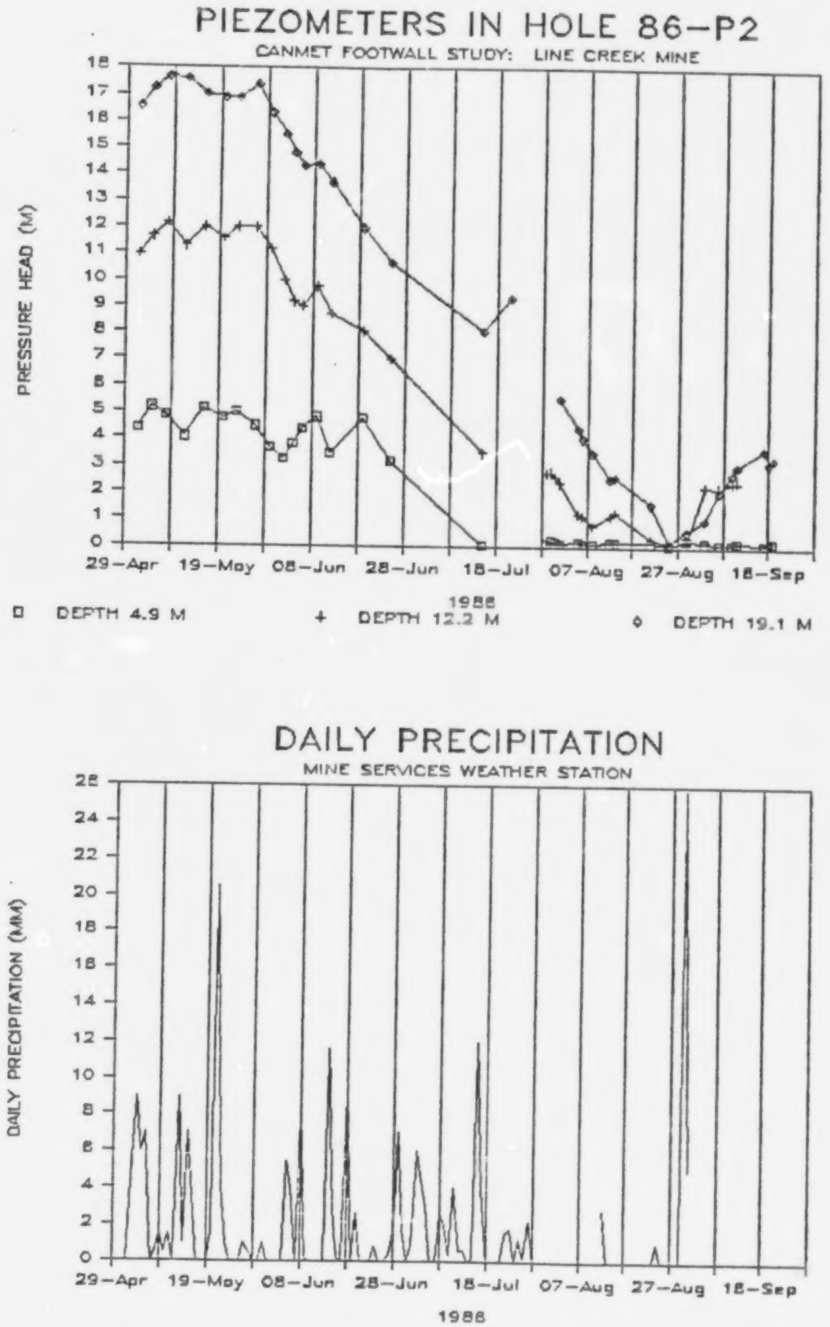

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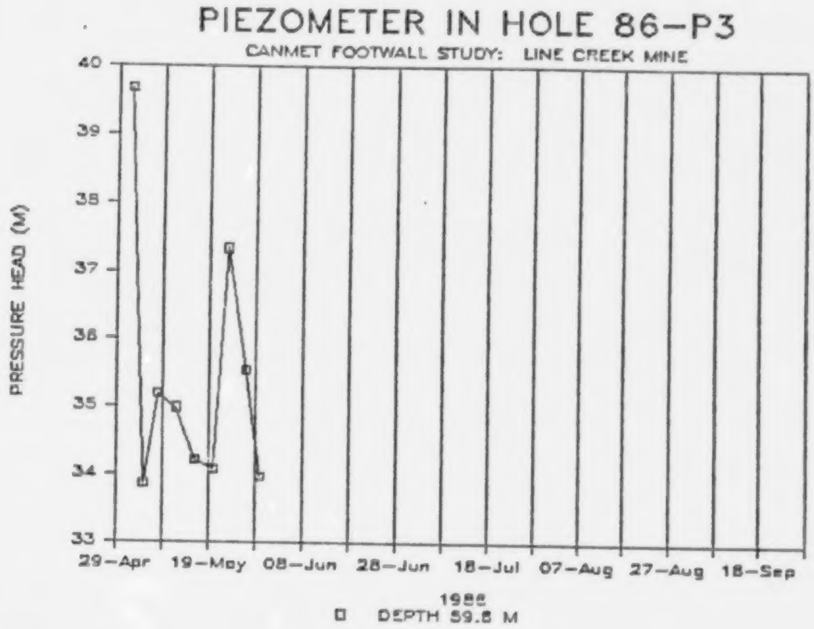
FIGURE 6-11b
RESULTS OF PIEZOMETRIC PRESSURE
MONITORING - HOLE 86-P2

SCALE	DATE 09/86	MADE	CHKD. GJB	JOB: VG03957	PLATE

HT12 - 79/05



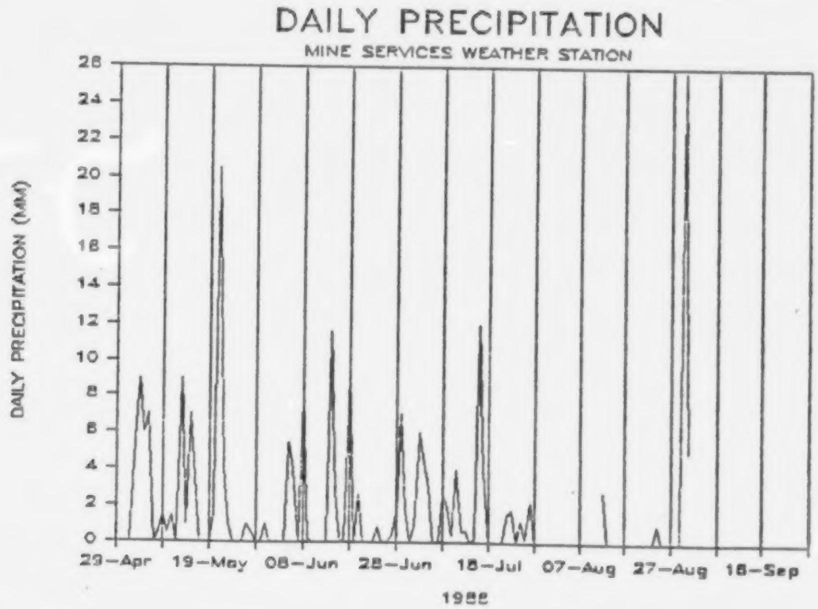


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FIGURE 6-11c
RESULTS OF PIEZOMETRIC PRESSURE
MONITORING - HOLE 86-P3

SCALE	DATE 09/86	MADE	CHKD. G.J.B.	JOB: VG03957	PLATE

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The piezometer in Hole 86-P3 indicated a high pressure head on installation and appears to be very sensitive to precipitation. This piezometer was lost on May 30, 1986, during blasting on the pit floor. Attempts are still underway by mine personnel to recover it and continue readings.

The piezometric surface inferred from the accumulated piezometric data, shown on Figure 6-3, implies that groundwater pressure dissipation occurs naturally as the pit floor is lowered. This is fortuitous and greatly benefits footwall stability. The relative absence of groundwater emanating from the footwall, either from discontinuities or from the installed drains, supports the contention that the actual volume of groundwater creating the pressure is relatively small. The rate of excavation may be sufficiently slow that pressure dissipation can occur naturally, without recourse to man-made drainage. This is not known at the present time, and could be a potentially dangerous experiment. Hence, the continued use of installed drainage is recommended at this time. Future data collected from the installed instrumentation, particularly when data over a complete annual cycle is available, could modify these conclusions.

6.6.5 Footwall Movement

Two inclinometers and two extensometers were utilized to monitor footwall movement. The inclinometer results are presented in Appendix 'F' and summarized in Figure 6-12. The extensometer results are summarized in Figure 6-13. Since Hole 86-E1 and 86-I1 are within 1 m of each other, it is reasonable to look at the results from these holes simultaneously. The same applies to Holes 86-E2 and 86-I2.

HOLE 86-I1 (movement perpendicular to footwall)

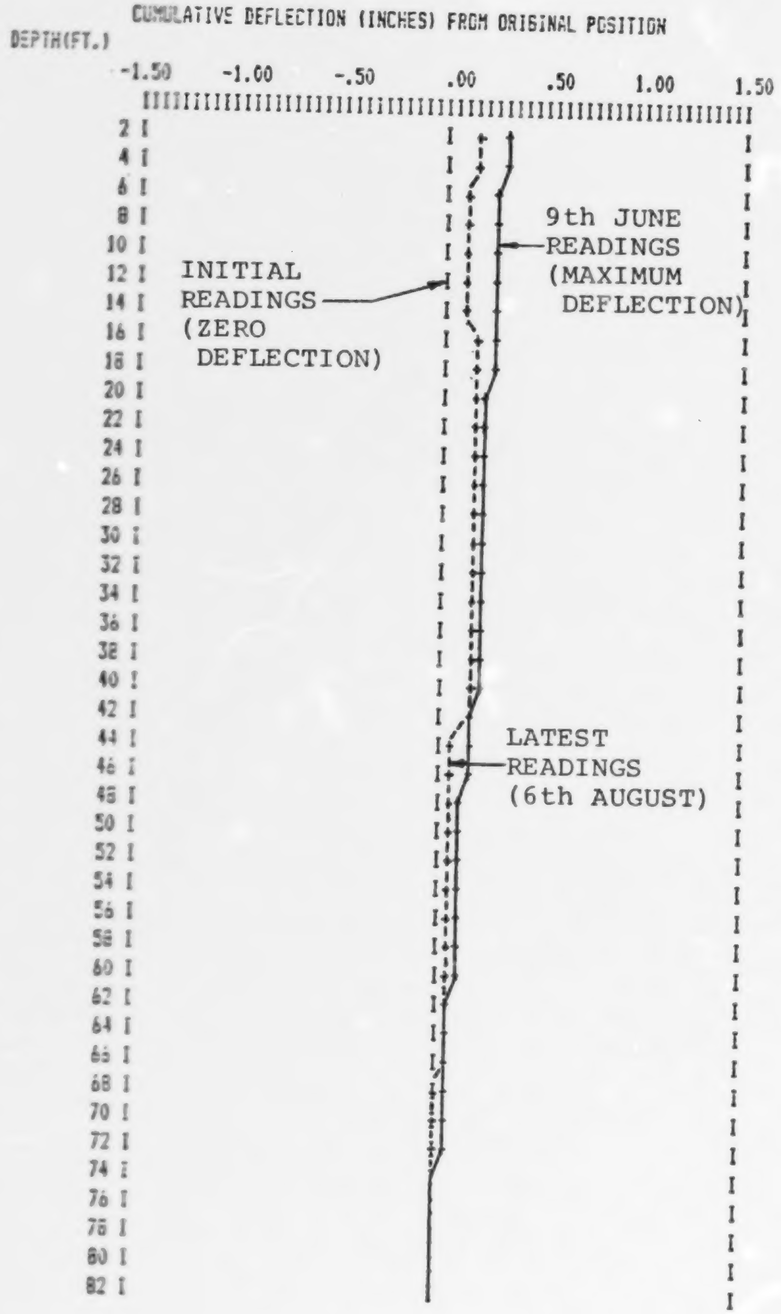

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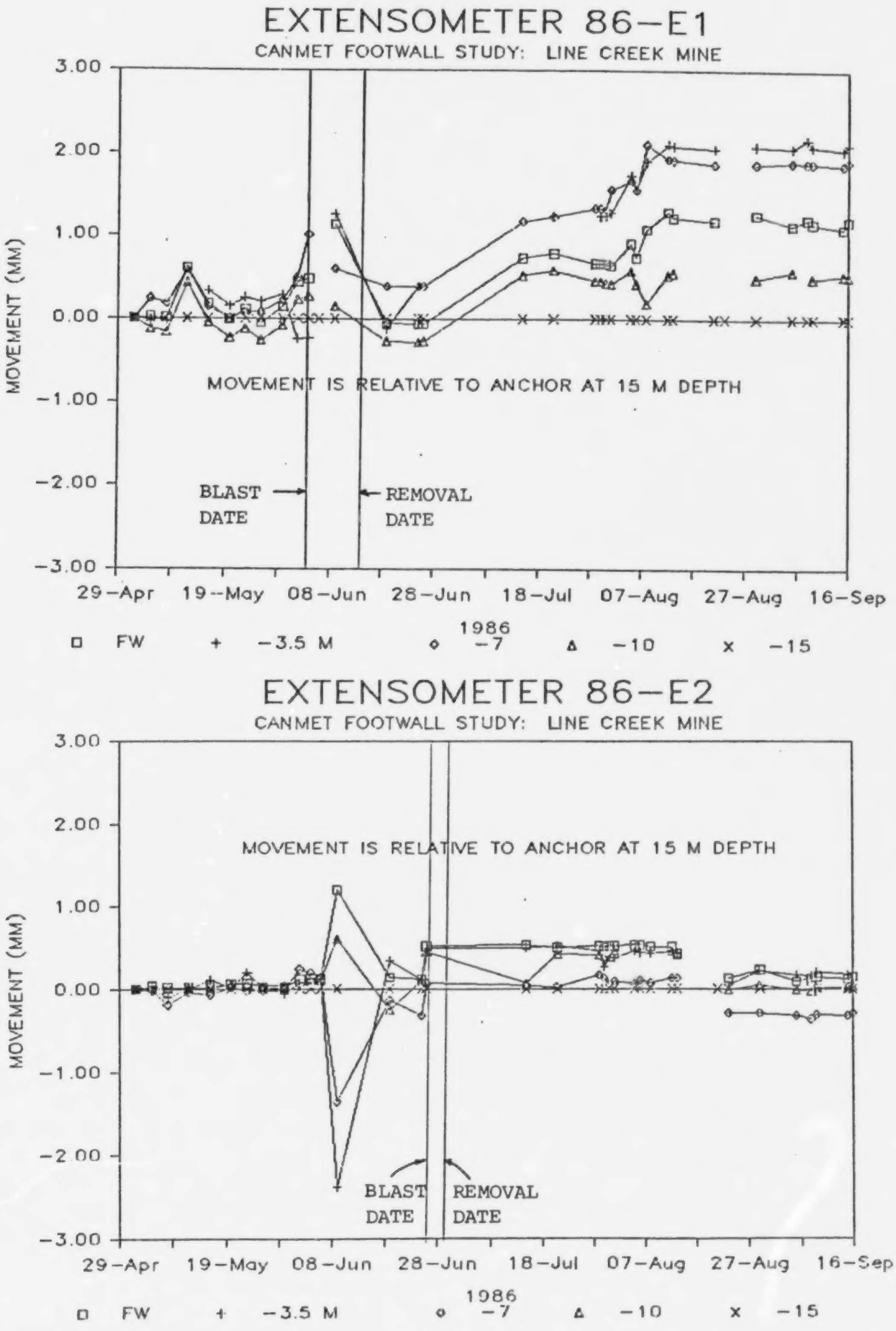
FIGURE 6-12
SUMMARY OF RESULTS OF INCLINOMETER MONITORING

SCALE NTS	DATE 10/86	MADE	CHKD. GTB	JOB: VG03957	PLATE



EXTENSOMETER 86-E1

CANMET FOOTWALL STUDY: LINE CREEK MINE

EXTENSOMETER 86-E2

CANMET FOOTWALL STUDY: LINE CREEK MINE

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FIGURE 6-13
RESULTS OF EXTENSOMETER
MONITORING-HOLES 86-E1, 86-E2

SCALE N.T.S.	DATE 09/86	MADE	CHKD. GJF	JOB: VG03957	PLATE

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Considering the data from Holes 86-E1 and 86-I1, both sets of data indicate a "kick" at the time of blasting adjacent to the holes. In the case of the extensometer, the blast appears to have caused temporary wild deflections, the readings settling down after two weeks to indicate slow but steady extensions, movement ceasing by mid-August. Maximum extensions in the order of 2 mm were recorded, but, oddly, the maximum did not occur at the footwall face, but at the 3.5 m deep anchor. This is difficult to explain, particularly as the 10 m, 7 m and 3.5 m anchors show increasing extension respectively. The implication is that compression on the top 3.5 m of the footwall has taken place. This implied compression is in the order of 1 mm. The inclinometer data indicates downslope movement of approximately 0.75 mm occurring immediately following the adjacent blast on June 4, 1986, this movement occurring predominantly on both the Upper and Lower Splits. However, subsequent readings indicate decreasing deflections, leading to the suspicion of movement of the inclinometer base (reference point). A comparison of the movements monitored using the two different techniques indicates that they are in general agreement, and minor downslope relaxation, accompanied by minor dilation, appears to have occurred as a result of excavation at the toe.

Considering the data from Holes 86-E2 and 86-I2, the extensometer appears to have been jolted severely on June 9, 1986. Immediate dilation, in the order of 0.5 mm, appears to have occurred following blasting on June 26, 1986, but no subsequent movement is evident. The apparent "displacement" of readings in mid-August is considered due to extensometer head repair carried out at that time, and is not considered to be a real phenomenon. The inclinometer data appears to indicate that the grout around the inclinometer casing failed to bond correctly; the nodes of the somewhat wild deflections are suspiciously adjacent to the casing couplings, where it is suspected the grout has, in fact, made a firm bond. Hence, the results from the inclinometer in Hole 86-I2 are considered invalid.

6.6.6 In Situ Stress State

The in situ stress state at the toe of the footwall has been determined using the C.S.I.R.O. Hollow Inclusion stress cell. A comprehensive report on this activity is presented in Appendix 'A'. The results are summarized in Table 6-7.

The results were not as originally expected; it was anticipated that the maximum principal direction would be approximately downdip, whereas it is now determined to be cross-dip to the south. Use of stress transformation equations give the following results for footwall stresses:

- Stress parallel to footwall, down-dip = 2.8 MPa
- Stress perpendicular to footwall = 2.5 MPa
- Stress along strike of footwall = 2.3 MPa

Thus, there is considerable stress normal to the footwall prior to excavation, knowledge of which is of great importance in the determination of footwall stability against buckling.

Assuming vertical stress, $\sigma_v = \gamma H$,
where γ = Bulk density of rock mass
H = Vertical height (or depth),
from the Line Creek Mine geometry and laboratory test results,

$$\sigma_v = 2.55 \text{ Mg/m}^3 \times 104 \text{ m}$$
$$= 2.60 \text{ MPa}$$

This very crude calculation tends to support the in situ stress results obtained using the C.S.I.R.O. cell.

TABLE 6-7: IN SITU STRESS STATE - LINE CREEK MINE FOOTWALL, 1798 LEVEL

PRINCIPAL STRESS	PRINCIPAL STRESS VALUE (MPa)	ORIENTATION	
		DIP DIRECTION (degrees)	DIP (degrees)
σ_1	3.1	146	45
σ_2	2.5	257	20
σ_3	1.8	003	38

6.6.7 Footwall Stability

The footwall at Line Creek has been the subject of extensive investigation to determine both present and anticipated future stability conditions, on the assumption that existing knowledge of geometry, strength and geology is correct. As discussed in Chapter 5, mining practice also has a major effect on footwall stability.

A comprehensive analysis of footwall stability must incorporate a determination of possible failure mechanisms, and this has been carried out for Line Creek. Potential failure mechanisms to be considered, outlined in Chapter 4 of this report, are as follows:

a) Translational - Cross Joints
- Plowing
- Daylighted Bedding

b) Buckling - Planar
- Curved

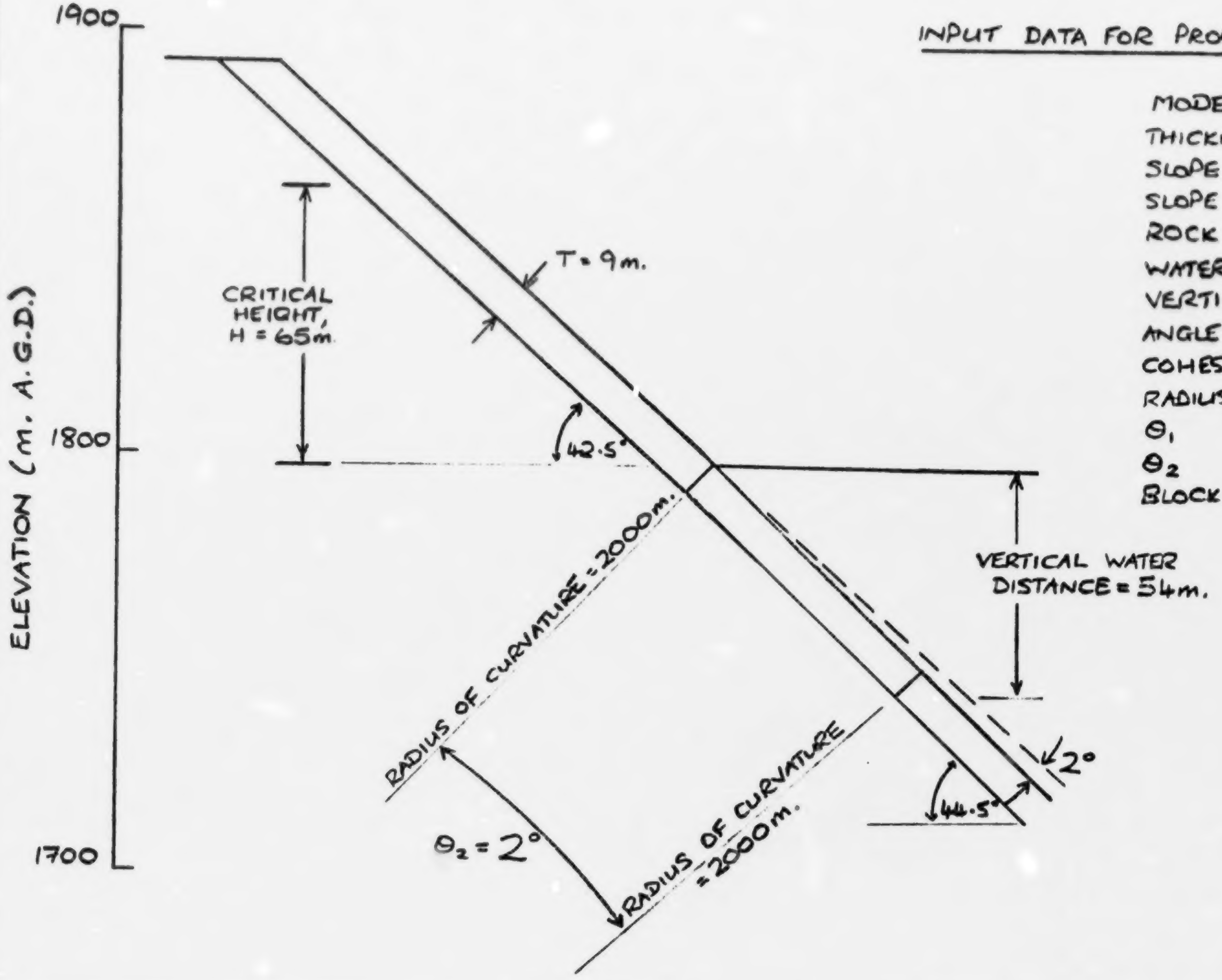
Discontinuity data collected for this study, indicates that cross joints dipping shallower than bedding are virtually non-existent (Figure 6-8). Hence, translational failure along cross joints is unlikely. The same discontiuity data indicates a near vertical joint set (joint set T3 in Figure 6-8) which could provide the kinematic possibility of plowing failure. However, the strength of the Footwall Sandstone is so high that this failure mechanism is considered unlikely. In addition, the driving force required to precipitate such a failure would be far in excess of that available on the Line Creek footwall slope.

The probability of localized failures due to daylighted bedding is a real one. Such failure mechanisms have occurred already on the Line Creek footwall due to the presence of small bedding pinchouts and strongly curved minor depositional rolls. A depositional roll obliquely crosses the footwall to the north of the drill hole locations, and frequent slab failures have occurred as a result of bedding exposure (Piteau & Associates (1980 & 1983)). Based on the known geometry below the present pit floor, no additional major problems are anticipated, but ongoing stability problems with this particular depositional roll are considered likely.

Both planar and curved buckling analysis techniques have been applied to the Line Creek footwall. The sections analyzed are Sections A-A and E-E, shown in Figures 6-14a and 6-14b. The locations of these sections are given in Figure 6-2.

Using the design charts for plane buckling of an elastic slab (Figure 4-8) and using the input data given in Figures 6-14a and 6-14b, it can be seen that the footwall is stable. However, the assumptions made for this analysis technique are somewhat sweeping, in particular, the assumptions of planar geometry and dry conditions. Hence, the optimum analytical tool to use for the Line Creek footwall is considered to be program CURVBUK.

A number of calculation runs using program CURVBUK have been made for both Sections A-A and E-E, using the input data given in Figures 6-14a and 6-14b. The program was run in Mode 3, and the series of runs on each sections was completed to determine the critical length of the upper slab, L1, and the corresponding force, P1, which would result in a factor of safety of unity. These


1900
1800
1700
ELEVATION (m. A.G.D.)
CRITICAL HEIGHT, H = 65m.
T = 9m.
42.5°
VERTICAL WATER DISTANCE = 54m.
RADIUS OF CURVATURE = 2000m.
RADIUS OF CURVATURE = 2000m.
θ2 = 2°
2°
44.5°

INPUT DATA FOR PROGRAM CURVBUK :

MODE	3
THICKNESS OF SLAB	9m.
SLOPE ANGLE ABOVE ROLL	42.5°
SLOPE ANGLE BELOW ROLL	44.5°
ROCK DENSITY	25kN/m.³
WATER DENSITY	9.81kN/m.³
VERTICAL WATER DISTANCE	54m.
ANGLE OF SHEARING RESISTANCE	40°
COHESION	0
RADIUS OF CURVATURE	2000m.
θ_1	0
θ_2	2°
BLOCK LENGTH 1	140m.

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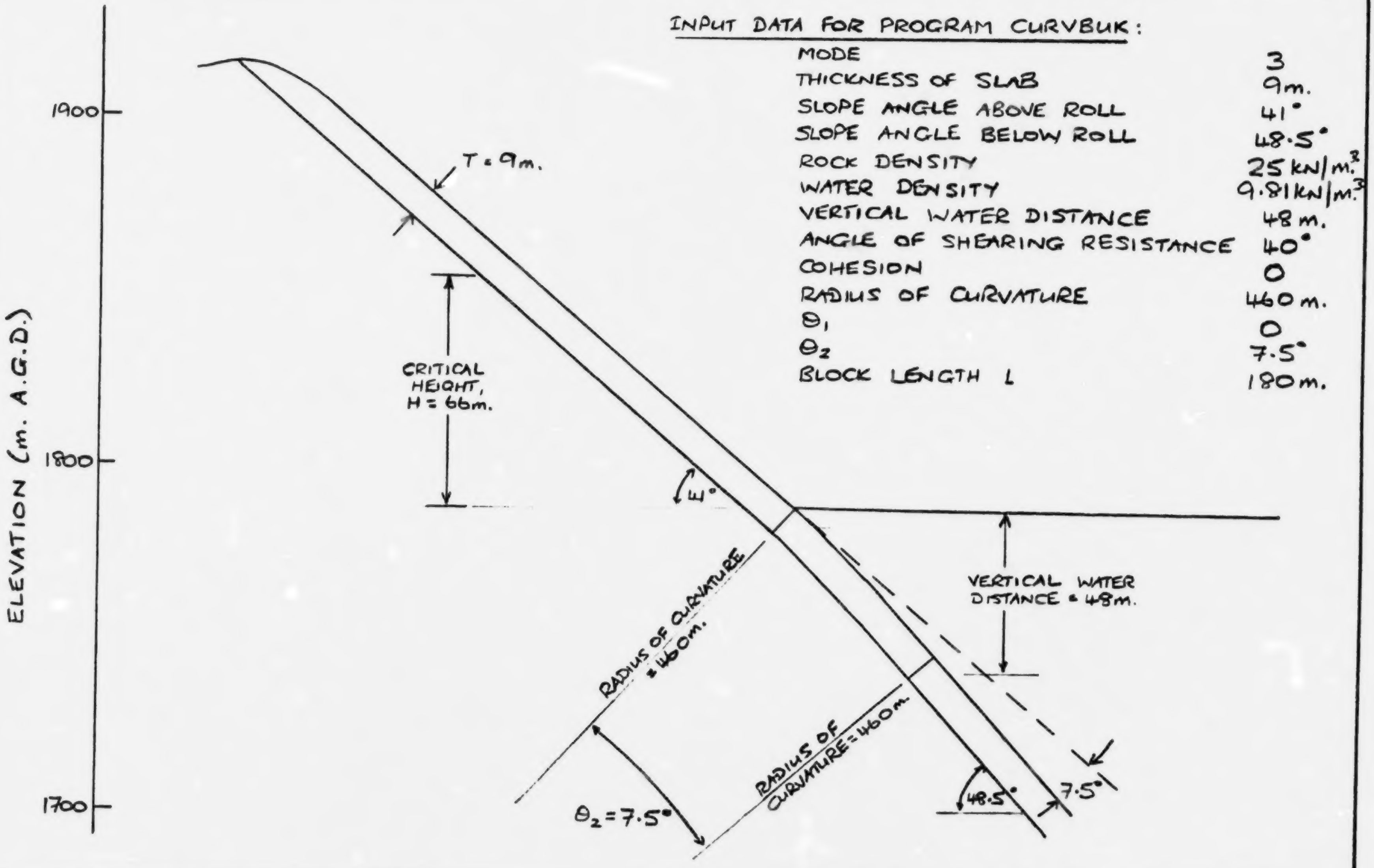
SECTION A-A: FIGURE 6-14a
BUCKLING ANALYSIS INPUT
DATA-LINE CREEK


ELEVATION (m. A.G.D.)
1900
1800
1700
T = 9m.
CRITICAL HEIGHT, H = 66m.
41°
VERTICAL WATER DISTANCE = 48m.
RADIUS OF CURVATURE = 460m.
RADIUS OF CURVATURE = 460m.
$\theta_2 = 7.5°$
48.5°
7.5°

INPUT DATA FOR PROGRAM CURVBUK:

MODE	3
THICKNESS OF SLAB	9m.
SLOPE ANGLE ABOVE ROLL	41°
SLOPE ANGLE BELOW ROLL	48.5°
ROCK DENSITY	25 kN/m.^{3}
WATER DENSITY	9.81 kN/m.^{3}
VERTICAL WATER DISTANCE	48 m.
ANGLE OF SHEARING RESISTANCE	40°
COHESION	0
RADIUS OF CURVATURE	460 m.
θ_1	0
θ_2	7.5°
BLOCK LENGTH L	180 m.

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FIGURE 6-14b
SECTION E-E: BUCKLING ANALYSIS INPUT DATA-LINE CREEK

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results are summarized in Figure 6-15. Using the P1 values as input data to equation (1) in Figure 4-2, reproduced below:

$$P = TH\gamma \left(1 - \frac{\mathrm{Tan}\ \emptyset}{F\ \tan\alpha}\right)$$

and substituting in the remaining parameter values, values for critical slope height, H, can be generated. The conclusions from this analytical process can thus be summarized as follows:

SECTION A-A - If overall slope height, H, is less than 65 m, force P1 will be less than the required value fo 1232 kN for a factor of safety of unity and the slope will be unstable.

SECTION E-E - If overall slope height, H, is less than 66 m, force P1 will be less than the required value of 517 kN for a factor of safety of unity, and the slope will be unstable.

At Section A-A, the present slope height is approximately 95 m, and at Section E-E, the present slope height is approximately 125 m. Hence, program CURVBUK indicates that large scale buckling failure of the Line Creek footwall is unlikely. An appreciation of relative stability, in terms of a factor of safety, can be obtained by comparing existing slope height to the critical slope height values generated above. This produces factors of safety of 1.46 and 1.89 for Sections A-A and E-E respectively. As the mine is deepened, providing that the footwall geometry and groundwater conditions do not differ from those anticipated and stated in this report, the

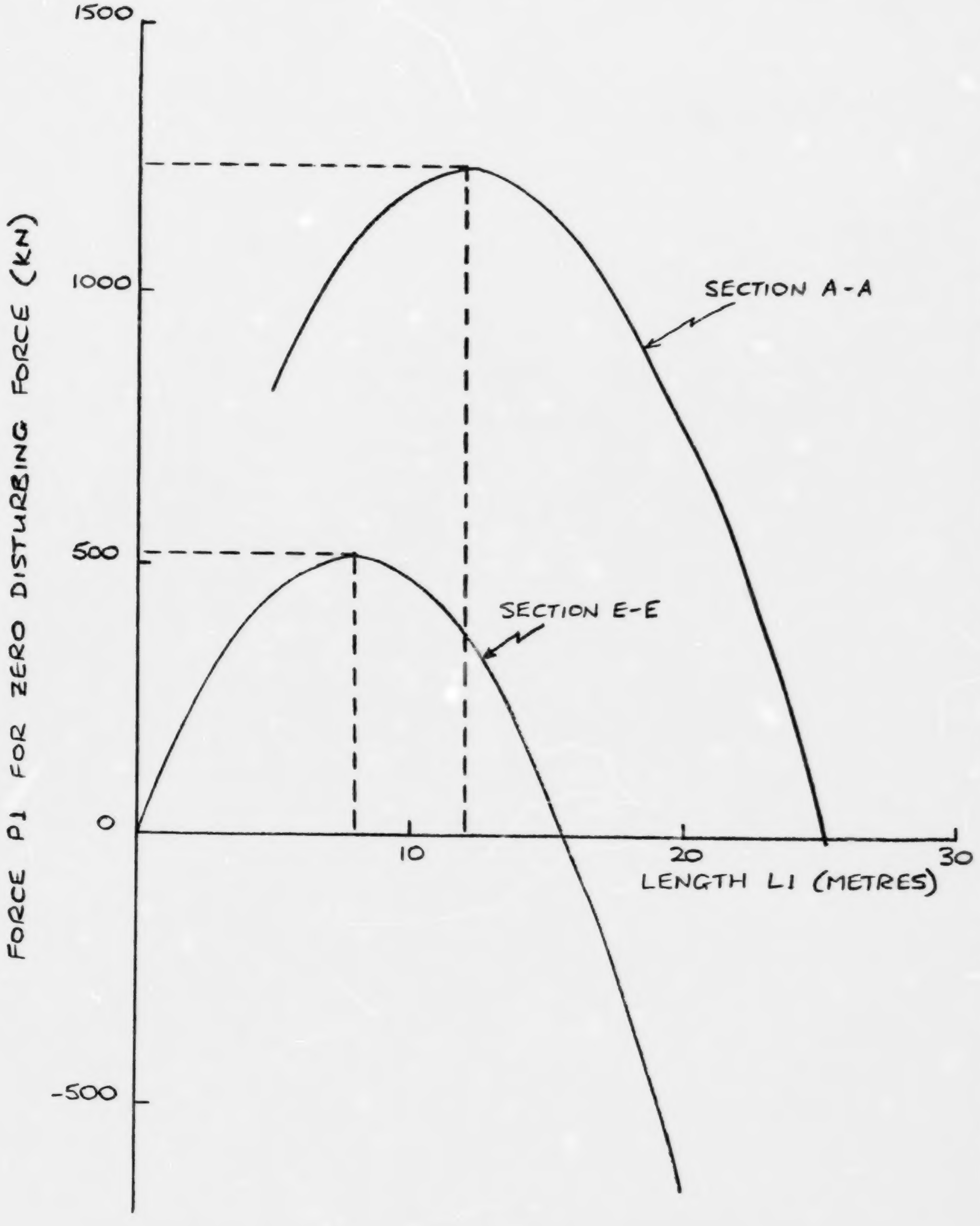

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FIGURE 6-15
RESULTS OF PROGRAM CURVBUK
APPLIED TO LINE CREEK

SCALE AS SHOWN	DATE 10/86	MADE GJB	CHKD.	JOB: VG03957	PLATE —

HT12 - 79/05

footwall should continue to be stable with respect to large scale buckling failure as a result of differential movement along the Upper Split. However, it would be prudent to re-analyze the footwall at regular intervals, say, after every second bench level removal, incorporating the most recent survey data at the footwall toe, the results of any subsequent monitored movement at the extensometers or inclinometers, and current piezometric data. Such a re-analysis would be a rapid, economical stability check using program CURVBUK.

In addition, it should be borne in mind that the CURVBUK analysis results indicate only conditional stability. That is, stability is conditional upon the availability of the force P1. This force comes from the slab above, and should cohesion develop along the base of the slab, or any other resisting mechanism to this force P1 develop, then instability could result. Hence, the field observation of downslope creep along the Upper Split is a very positive attribute to the stability of the footwall.

6.6.8 Recommendations

The Line Creek footwall is in a state of conditional overall stability, relying on downslope loading from the slope above. This condition has occurred due to the presence of groundwater pressures at the footwall toe, which appear to self-dissipate as the base of the pit is lowered. Small scale instability, due to the local presence of depositional rolls and bedding pinchouts, will continue to be a nuisance throughout anticipated mine life. Hence, the following recommendations are made, with the aim of maintaining stable footwall conditions:

1) Ongoing monitoring of the installed extensometers 86-E1 and 86-E2, and the inclinometer 86-I1, should be carried out to observe footwall movement and confirm ongoing relaxation downslope as the mine is deepened. Movements of the order of 1 mm should be anticipated for each bench level, occurring primarily after removal of toe materials. This downslope creep improves stability against buckling failure.

2) Ongoing monitoring of groundwater pressures in the footwall should be carried out by means of the pneumatic piezometers in holes 86-P1 and 86-P2. Serious attempts should be made to relocate 86-P3 in order to continue monitoring of the piezometer in that hole. Groundwater pressures are anticipated to dissipate slowly as the mine is deepened. However, this process should be enhanced by the installation of drainage measures in the toe of the footwall, following the excavation of each bench. These drainage measures should comprise either sub-horizontal drains extending 30 m into the footwall, or drain perpendicular to bedding extending 20 m into the footwall. Drainage intervals should be maximum 10 m along the footwall toe. Providing the holes stay open, no lining is considered necessary. It should be borne in mind that flow from the drains may be small; nevertheless, groundwater pressures could be reduced significantly.

3) The footwall geometry below the pit floor should be monitored using drilling and geophysical techniques. It may be appropriate to test some of the newer geophysical techniques outlined in this report. An accurate assessment of footwall geometry prior to exposure can forewarn mine staff of impending stability problems.

4) The overall stability of the footwall should be reviewed, following removal of every second bench level (25 m vertical height), using program CURVBUK, and incorporating updated geometry, movement and groundwater data.

5) Minor failures on depositional rolls and bedding pinchouts should be controlled using standard anchoring techniques. The current method used at the mine, incorporating sandblasted shovel cable as grouted dowels, is considered appropriate and cost effective. Dowel lengths should be at least twice the thickness of the roll to ensure an adequate bond length. Spacing and orientation will be site specific, bearing in mind the comments and recommendations outlined in Section 5.5. The determination of the extent of small scale rolls beneath the pit floor should be investigated using state-of-the-art geophysical techniques and/or precision drilling (Sections 2.2 and 3.2 of this report).

7.0 CONCLUDING REMARKS AND RECOMMENDATIONS

7.1 GENERAL

The footwall design process is an ongoing one involving continuing refinement of data concerning wall performance and geometry combined with ongoing solution of problems as they arise. This report has addressed the various elements of this process which includes exploration, monitoring analysis and design and investigation. All of these elements are required as part of the ongoing observational method which has been implicitly used during mining of footwalls throughout the world.

This project has examined the various elements of footwall design and mining and has provided several new tools and techniques which are applicable to the different design elements. Significant developments in the course of this work have included:

a) Program CURVBUK which offers the first practical methods for detailed analysis of curved slopes subject to buckling.

b) Further development of methods for analyzing plane slopes subject to buckling and development of design charts.

c) The first in situ stress measurements in a surface coal mine in the Rockies.

d) Detailed monitoring of footwall movements and pore pressures to provide the start of a data base which will help to understand footwall behaviour.

e) Development of design stability charts for various stability modes.

7.2 EXPLORATION

A comprehensive exploration program should incorporate the determination of potential footwall geometry, geology, hydrogeological conditions both in and behind the footwall, and the determination of the in situ stress state. In most exploration programs the above parameters are considered, but the degree of accuracy and precision could be improved by the use of current technology.

In particular, the following recommendations are made:

1) All holes should be oriented. In addition, the effect of minor lateral drilling variations could be minimized by drilling perpendicular to bedding, where possible.

2) The use of computerized axial tomography techniques may provide useful information in some situations of high amplitude faulting or bedding pinchout.

3) The depositional environment of the footwall materials should be thoroughly investigated and understood. Depositional features in any footwall exposures should be carefully mapped with a view to determining feature trends on the eventual footwall face.

4) The in situ permeability of the strata forming, and below, the footwall should be determined using carefully positioned

packer tests. The test intervals should be sufficient to differentiate permeability values between different strata types noted from accurate borehole logging. Hence, the use of double and triple packer systems, particularly the latter for use with a wireline system, are strongly recommended, packer tests being carried out following drilling of the exploration hole to full depth.

5) Groundwater pressures in the footwall strata, and in the strata below, should be monitored by the use of piezometers. These instruments should be positioned and isolated in hydrogeological sequences defined from the packer testing. Rapid response piezometers (pneumatic or electrical) are recommended. Measurements in some holes should be carried out well behind the footwall face.

6) The current study has shown the usefulness of in situ stress determinations to assist in assessing footwall behaviour. Unfortunately, stress determination at depth in a borehole is still a problem with most of the available techniques. Existing techniques, including the C.S.I.R.O. cell, work best at maximum borehole depths of 10 to 15 m. Hydraulic fracturing is feasible at greater depth, but difficult to interpret and does not give the complete stress tensor. In some cases, adits or favourable topography will allow use of existing techniques while in other cases determinations can be made during mining or extrapolations made from other available data.

7) Prior to the commencement of mining activity, a detailed footwall topographic map should be generated, together with

sections, incorporating all data accumulated as a result of exploration work. The magnitude of possible geometric problems should be assessed and used in considering mitigation alternatives to solve problems as they are encountered during mining.

7.3 MONITORING

During the mining process, adequate monitoring of footwall geometrical variations, movements, stress changes and groundwater conditions should be routinely implemented. The following recommendations are specific to such a program:

1) Detailed topographic surveying of the footwall should be completed following the exposure of each bench level. Thus, the detailed footwall topographic map and sections developed as part of the exploration program should be confirmed and/or modified as each bench is removed.

2) Additional footwall exploration at the toe of the excavation should take place routinely as each bench is removed. This program would provide data concerning both large and small scale variations (large scale curvature and small scale geometry problems). This exploration could incorporate the use of closely spaced, surveyed, oriented drillholes, using standard mine drilling equipment, down which geophysical tools should be run to determine hole geology. The choice of geophysical tools would be site specific, depending on local conditions. Achieving adequate hole density to allow resolution of all potential features greater than, say, 0.8 m high (i.e. involving failure of a 0.8 m rock slab) is likely to be

economically difficult with existing technology. Alternatives are to concentrate on known problem areas, accepting the risk of undetected problems elsewhere, or to consider the use of alternative techniques as discussed below.

3) The use of high resolution continuous seismic profiling, run across and perpendicular to the footwall toe, and borehole radar should be thoroughly investigated and tested. Current indications are that these techniques may have sufficient resolution to map small scale features.

4) Footwall movement, in the form of downslope creep, should be monitored using borehole extensometers and/or inclinometers. Since movements are anticipated to be particularly small, survey methods may be inappropriate. The spacing of the instrumentation would be site specific, depending on local conditions, but placement of an instrumentation group along the footwall crest, following initial exposure, is considered appropriate, followed by additional instrumentation downslope during mining.

5) The determination of the in situ stress state in a footwall, and its variation during the mining process is useful in shedding light on potential stability problems. However, in its current state, the techniques used are somewhat expensive, and occasionally produce questionable results. The C.S.I.R.O. cell appears to be the best choice at the present time, and it is recommended that stress measurements using this cell be made in the footwall at regular intervals during mine life (say, every 2 years) to keep a check on changing stress conditions.

The use of a C.S.I.R.O. cell left in-place to monitor stress changes, may be used to monitor stress changes with time and ongoing mining.

6) It is recommended that all piezometers used for monitoring groundwater pressures be quick-response types. Use of continuous recording to check short duration pressure peaks should be considered. The magnitude of transient peaks and troughs, due to rainfall, should be carefully monitored, since these could have a major effect on stability.

7.4 ANALYTICAL PROCESSES

Translational failure modes have been considered by many workers in the past, and stability charts have already been produced for cross-joint and daylighted bedding cases, (Brawner, Pentz & Sharp (1971), Hoek & Bray (1983)). A useful format for these stability charts is outlined in this report (Figure 4-3(b)). Buckling modes of failure are not so well researched, and efforts have been concentrated in this direction in the present study. Analytical techniques for dealing with potential buckling failure mechanisms have been developed for application to both plane and curved footwalls. Design charts are presented in Figures 4-8, 4-9, 4-10, 4-15 and 4-16, and stability tables are given in Appendix 'C'. Recommendations arising from work carried out for this aspect of the study are as follows:

1) Groundwater pressure plays a very significant roll in controlling footwall stability. For typical conditions in

Western Canada, we recommend that ongoing installation of drainage at the toe of the footwall should be standard practice.

2) In the analysis of curved slopes, Corbyn's method (Section 4.3.2.2) provides only a preliminary simplified approach and may be misleading in some geometries. In general, it is recommended that program CURVBUK (Appendix 'B') be used for a comprehensive analysis. This program has been developed and tested as part of this study.

7.5 IMPLEMENTATION

General recommendations with regard to design implementation and operational constraints are as follows:

1) It is recommended that drainage be installed on all footwalls, even where natural drainage is apparently successful in reducing groundwater pressures. The effectiveness of the drainage measures employed should be monitored using rapid-response piezometers.

2) With regard to blasting practice, blast holes should not penetrate the basal coal seam, to enable the seam to act as a buffer. Toe charges and charges per delay should be reduced as much as possible. Choke blasting without a free face should not be done near the footwall.

3) Simultaneous exposure of long lengths of the footwall should be avoided in critical areas. Instead, excavation sequencing

should be designed to allow visual checks on small exposed areas prior to large scale exposure.

4) Both tensioned and untensioned anchors may be considered to enhance footwall stability in critical areas. Appropriate care should be taken in the selection of anchor type, corrosion protection, orientation and bond length, bearing in mind the design life of the anchor and the intended stress to which it will be, or may become, subjected.

5) Benches, if employed at all, should be positioned carefully to avoid undercutting the footwall.

7.6 FURTHER WORK

We recommend further work as follows:

- Long-term monitoring of a number of footwalls will provide valuable data on performance characteristics and will assist materially in using monitoring data to assess stability conditions.

- Development and field trials of seismic and radar methods to establish footwall geometry below the pit floor.

With regard to the determination of in situ stress at depth, the use of the C.S.I.R.O. cell becomes difficult, if not impossible, to use beyond depths of approximately 10 m. While the use of the cell is the most reliable of current methods, field trials to compare the cell with other, more remote, techniques (i.e. Serata Stressmeter) are encouraged.

7.7 CLOSURE

Hardy Associates (1978) Ltd. have enjoyed completing this important and interesting study, and trust the results and recommendations contained herein provide appropriate answers to current problems, and, at the same time, inspire further questioning and research into the topic of footwall stability. We believe that this study provides important new tools and methods for the mining industry.

Hardy Associates (1978) Ltd. would like to thank the staff of Crows Nest Resources Ltd., Line Creek Mine, for their most valuable input and assistance throughout this study. The assistance of CANMET in funding this study and the support of Dr. R. Singhal, P. Eng. are gratefully acknowledged.

Yours truly,

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Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DEVELOPMENT OF DESIGN CRITERIA FOR STEEPLY DIPPING FOOTWALL STABILITY IN MOUNTAIN REGIONS (UP-H-221)

APPENDICES TO FINAL REPORT

BY

HARDY ASSOCIATES (1978) LTD.
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DEVELOPMENT OF DESIGN CRITERIA FOR STEEPLY DIPPING FOOTWALL STABILITY IN MOUNTAIN REGIONS

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STRESS MEASUREMENT AT LINE CREEK MINE -
REPORT PREPARED BY INTERNATIONAL MINING SERVICES, INC.

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CANMET FOOTWALL STABILITY STUDY
STRESS MEASUREMENT
AT LINE CREEK MINE

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July 1986

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STRESS MEASUREMENT AT LINE CREEK MINE

1. Introduction

Stress measurement using the Commonwealth Scientific Industrial Research Organization Hollow Inclusion Cell (CSIRO HI Cell) was undertaken at Crows Nest Resources' Line Creek Mine between 18 - 22 April 1986. The stress measurement was undertaken by International Mining Services Inc. in conjunction with Hardy Associates (1978) Ltd. as part of the CANMET Footwall Stability Study. Drilling and overcoring were carried out by Drilcor Industries Ltd. of Vancouver.

Four stress measurements were attempted in borehole 86-S1 which is located in the sandstone footwall on the 1798 m bench. Hole 86-S1 has an approximate dip of 35° downwards, perpendicular to the strike of the footwall sandstone (246° azimuth). The footwall dips at approximately 45°/066° and has a height of 104 m directly above borehole 86-S1. The highest point of the footwall is 115 m above the 1798 m level, to the north of 86-S1, Figure 1.

The overcoring procedure and method of analysis are discussed in references 1 and 2. The theory and application of the HI Cell is also fully discussed elsewhere (3,4,5 & 6). Therefore, only details pertinent to this study will be discussed in the following sections. No discussion of the stresses in relation to geological features or residual tectonic stresses has been included.

2. H.I. Cell Installation and Overcoring

Four CSIRO HI Cells were installed in borehole 86-S1. Figure 2 indicates the relative location of each cell in borehole 86-S1 and Table 1 summarizes all relevant cell data.

The major problem encountered during the installation of the HI Cells was cleaning the EX pilot hole prior to cell installation. Clearing the hole of drill cuttings and moisture became harder as the hole deepened with each subsequent installation. This is to be expected with a downward dipping hole. Drill cuttings and moisture readily accumulate at the base of both the EX pilot hole and the 150 mm overcore hole. Clearing the hole would be improved if 150 mm drill rods were available. This would reduce the annulus around the rods and hence increase the flow rate of the flushing fluid. The drilling rods used were BW rods with 150 mm stabilizers.

Inspection of the sectioned cores, Plates 1 and 2, reveals that there are a minimal number of air bubbles entrained in the resin. However, subtle changes in the reflectivity of resin surface does show where the debonding appears to have occurred.

Both test cells 3 and 4 appear to have debonded during overcoring. This can probably be directly attributed to moisture and drill cuttings remaining in the hole during cell installation.

Drilling was undertaken by Drilcor Industries Ltd. using a hydraulic powered Winkie drill with hand feed. No major problems occurred during drilling and overcoring, although the Winkie did stall on some occasions.

Monitoring of overcore strains was carried out using IMS's Measurement Group P-3500 strain indicator and switch box. Results from the overcoring are presented in Figures 3 to 6 and in Appendix I.

Strains recorded during overcore test #1 are erratic, Figure 3. There is not a satisfactory explanation for this behaviour. Most probably it is due to poor junctions or soldering in the cell itself or at the strain indicator. It has been possible to undertake some analysis of overcore #1 results. HI Cell #1 was also inadvertently installed upside down and this has been accounted for in the analysis.

Overcore #2 was the most successful of the four tests. The shape of the strain/time curve is typical of high quality overcore curves (5) although apparently gauges 8 and 9 debonded during overcoring, Figure 4.

Overcores 3 and 4 both debonded before overcoring was complete, probably due to the presence of moisture and dirt in the hole during HI Cell installation. It has proved impossible to interpret the results from overcore #4, Figure 6. However, it appears likely that cell #3 debonded at or near the stress peak; the peak value for gauge 2 test #2 is 328 microstrain compared to 315 microstrain for the same gauge in test #3. Therefore, the peak values of the overcore strains for test #3 have been used for analysis purposes.

Overcore strains used for the analysis of stresses and stress directions are summarized in Table 3.

3. Biaxial Tests and Results

Two series of biaxial tests were undertaken. The results are presented in Figures 7 to 11 and Appendix II. Tests were undertaken on overcores #2 and #4. Overcore #1 broke up either during overcoring or during removal from the overcore barrel. Overcore #3 was too short for the biaxial cell.

The first series of tests were carried out using a biaxial cell rented from Solinst Canada Inc. These tests were undertaken on overcores #2 and #4, Figures 7 and 8. Analysis of the results indicates an increasing elastic modulus with increasing load, Figure 9. This probably results from the presence of air bubbles in the biaxial cell. A second biaxial cell was acquired in an effort to obtain a more reliable Young's modulus and Poisson's ratio. These tests were undertaken on overcore #2. The results are presented in Figures 10 and 11.

The material properties used for the determination of stresses from the overcore strains were:

Young's modulus = 19.9 GPa (2.88×10^6 psi)
Poisson's ratio = .25

These results are derived from the average unloading modulus on biaxial test #2C in the load range 1.72 - 6.9 MPa. This load range is close to that existing in the sandstone footwall. The methodology used in the calculation of the material properties is that of Jalkanen (2) and Duncan Fama (3). Unfortunately laboratory determination of the elastic constants has not, as yet, been undertaken and are therefore not available for comparison.

4. Stress Determination and Discussion of Results

The results from the overcoring were processed using IMS's HI cell analysis program (2). Several analyses have been made to test the sensitivity of the results to elastic constants and possible inaccuracies in the overcore strain measurement. The results of some of the analyses are summarized in Table 4.

With the exception of gauges 8 and 9 which possibly debonded during overcoring, the results from overcore #2 are of exceptionally high quality, Figure 4. The results from the analysis of overcore #2 strains must therefore be considered to be the most reliable of the individual tests. However, the value of the minor principal stress is very sensitive to the value of the strain for gauge 9. This is shown in Tables 3 and 4. This is unusual for the analysis of stresses and is probably due to gauge 9 lying along the calculated direction of the minor principal stress.

In an effort to confirm the results from overcore #2, analyses were run on overcores #1 and #3. In addition a combined analysis of runs 1.1 and 2.4 was carried out, Table 4. The principal stress direction for runs 1.1, 2.4 and 1/2 are plotted in Figure 12.

Table 4 also gives the subsidiary principal stresses, that is the stresses in the plane of footwall,the normal stress and the North-South stress. In all cases, the major subsidiary principal stress is along the dip of the footwall, as expected.

Due to the sensitivity of the overcore #2 results to the inclusion or omission of gauge 9 strain readings, and the fact that the results from overcore #1 are not sensitive to the inclusion or omission of strain readings, the results from the combination of the two tests are probably the most reliable. In addition, there is a close correlation between the principal stress directions of the combined analysis and those from overcore #2.

5. Conclusion

Four overcoring tests were undertaken in Line Creek Mine's sandstone footwall bench 1798.

Difficulties were experienced during the testing in clearing the EX pilot hole prior to cell installation. This probably resulted in cells #3 and #4 debonding during overcoring.

The results from overcores #1 and #2 are relatively close. These have therefore been combined to produce the best estimate for the stresses in the sandstone footwall. The results of this analysis are listed below.

PRINCIPAL STRESSES			PRINCIPAL STRESS DIRECTIONS			SUBSIDIARY PRINCIPAL STRESSES		
σ_1 MPa (psi)	σ_2 MPa (psi)	σ_3 MPa (psi)	σ_1 Brg Dip	σ_2 Brg Dip	σ_3 Brg Dip	$\sigma_{//}$ MPa (psi)	$\sigma_{\perp}$ MPa (psi)	σ_{NS} MPa (psi)
3.1 (456)	2.5 (369)	1.8 (267)	146 45	257 20	3 38	2.8 (400)	2.5 (356)	2.3 (334)

Young's modulus = 19.9 GPa (2.88×10^6 psi)

Poisson's ratio = .25

Bearing in degrees clockwise from North

Dip in degrees, positive downwards

6. References

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5. Blackwood, R.L., 1978, Diagnostic Stress-relief Curves in Stress Measurement by Overcoring, Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 15, pp. 205-209.
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Tables

Table 1
H.J. Cell Data

Test #	CSIRO Cell # m	Depth 150 mm m	Depth EX Hole m	Depth Cell m
1	2120	2.69	3.40	3.12
2	2118	3.31	3.97	3.73
3	2115	3.92	4.57	4.40
4[1]	2119	4.15	4.86	4.67

Hole 86-S1: Bearing = 246°

Dip = 35°

Footwall: Strike Bearing = 336°

Dip Bearing = 066°

Dip = 43.5°

NOTES: 1. Probable error in depth measurement for test #4.

Table 2
CSIRO Cell Installation Procedure

GENERAL

- Check the ambient temperature
- Test the grout setting time
- Inspect the 6" core from the hole

FOR EACH CELL

1. **Measure**
   - Depth of 6" hole
   - Depth of EX hole
   - Length of EX core
     - mark these on the installation rods
2. **Measure air and hole temperatures.**
3. **Select the location of the cell (centre line).**
4. **Calculate**
   - Length of EX hole
   - Length from ℄ to end of EX
   - Spacer length = [℄ to end EX] - [Compressed length to ℄] = 9 cm.
   - Total expanded length of cell (incl. spacer) = spacer length + 30 cm.
5. **Mark on rods:**
   i) Depth 6" hole - Total cell length
   ii) Depth EX hole - Total cell length
   iii) Depth EX hole - Compressed cell length [7 cm less than ii)]
6. **Clean EX hole:**
   - Dry
   - Degrease
7. **Check cell for defects:**
   - gauge resistance
   - trip wire
   - thermister
8. **Prepare cell**
   - cut notches in seals
   - file lugs
   - sandpaper surface
   - CHECK MEASUREMENTS
   - degrease
9. **Grease installation rods.**
10. **Mix Grout.**
11. **Install cell**
    - push SLOWLY to break shear pins and prevent air bubbles
    - check cell alignment
    - wedge installation rods
12. **CHECK GROUT BEFORE REMOVAL.**

Table 3
CSIRO Overcore Results

TEST #	RUN #	1 AXIAL	2 CIRC.	3 ANGLE	4 ANGLE	5 ANGLE	6 CIRC.	7 AXIAL	8 CIRC.	9 ANGLE
1	1	57	352	204	205	–	223	70	156	78
2	1	60	328	173	259	164	218	75	18	37
2	2	60	328	173	259	164	218	75	–	37
2	3	60	328	173	259	164	218	75	–	–
2	4	60	328	173	259	164	218	75	–	87[1]
3	1	90	315	140	200	146	138	110	–	135
3	2	90	315	140	200	146	138	110	–	–
3	3	90	315	140	200	146	–	110	–	135

NOTES: 1. Peak strain for gauge 9.

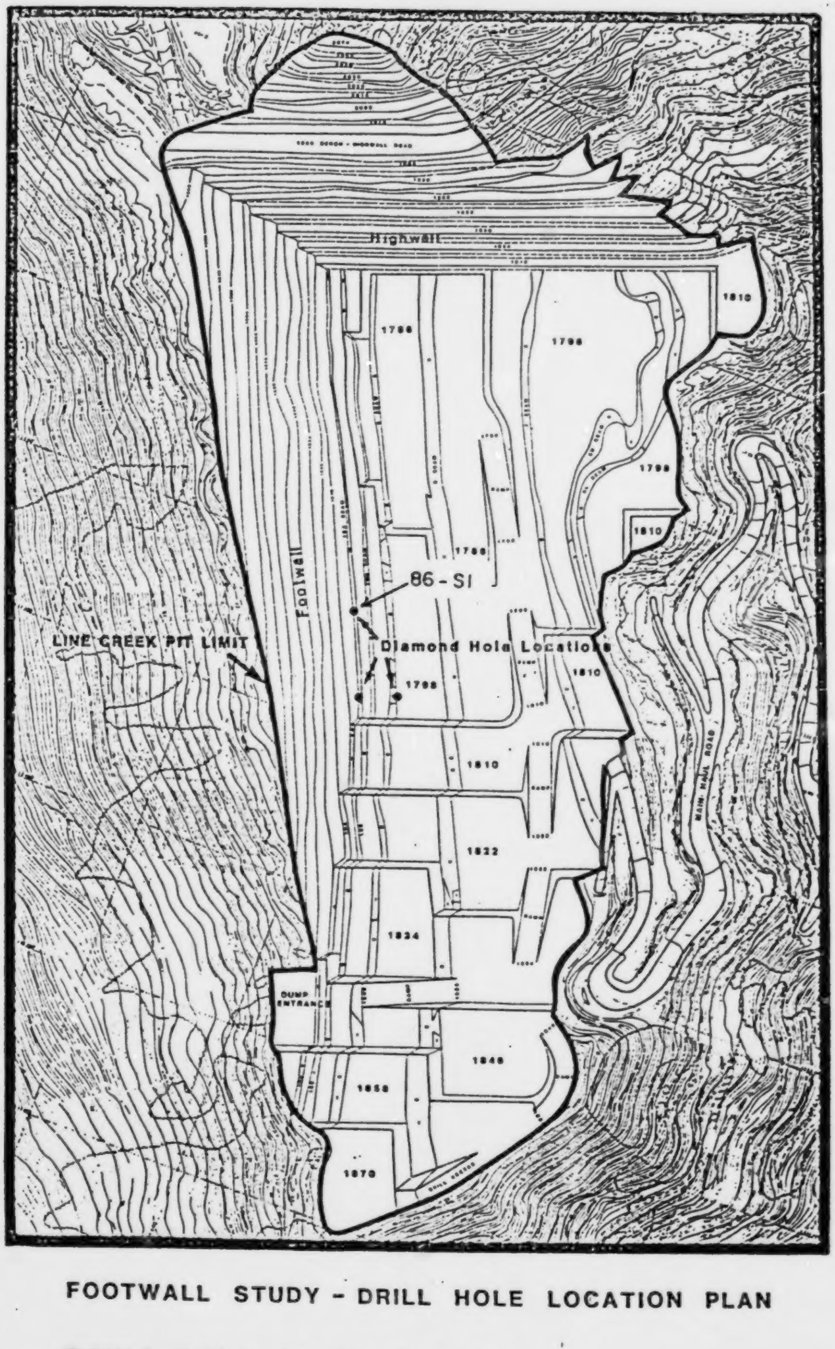
Table 4
CSIRO Analysis Results

TEST	RUN	PRINCIPAL STRESSES						SUBSIDIARY STRESSES[1]		
#	#	σ_1	σ_2	σ_3	σ_1	σ_2	σ_3	$\sigma_{\parallel}$[2]	$\sigma_{\perp}$[3]	σ_{NS}
		MPa (psi)	MPa (psi)	MPa (psi)	Brg Dip	Brg Dip	Brg Dip	MPa (psi)	MPa (psi)	MPa (psi)
1	1[4]	3.1 (453)	2.6 (381)	1.8 (264)	117 59	266 35	18 15	2.9 (423)	2.6 (383)	2.0 (292)
2	1	3.2 (460)	2.4 (343)	1.1 (158)	161 45	263 13	5 43	2.4 (345)	2.2 (320)	2.0 (296)
2	2	3.2 (461)	2.5 (363)	0.9 (133)	159 45	265 15	9 40	2.3 (333)	2.2 (319)	1.9 (278)
2	3	3.0 (438)	2.0 (287)	0.0 (-14)	151 52	257 19	8 45	1.8 (266)	1.6 (231)	1.5 (212)
2	4[5]	3.3 (476)	2.5 (357)	1.4 (201)	165 50	270 12	10 38	2.5 (364)	2.5 (361)	2.1 (309)
3	1	3.4 (486)	2.4 (341)	8.5 (124)	208 62	108 5	15 27	2.2 (322)	2.9 (426)	1.4 (203)
3	2	3.2 (462)	2.3 (333)	0.5 (78)	200 60	106 3	15 29	2.0 (294)	2.7 (393)	1.2 (175)
3	3	3.3 (484)	2.4 (349)	1.1 (155)	206 62	107 5	15 28	2.3 (332)	2.9 (425)	1.6 (231)
1/2	–[6]	3.1 (456)	2.5 (369)	1.8 (267)	146 45	257 20	3 38	2.8 (400)	2.5 (356)	2.3 (334)

NOTES: Bearings are positive clockwise from north.
Dips are positive down from horizontal.

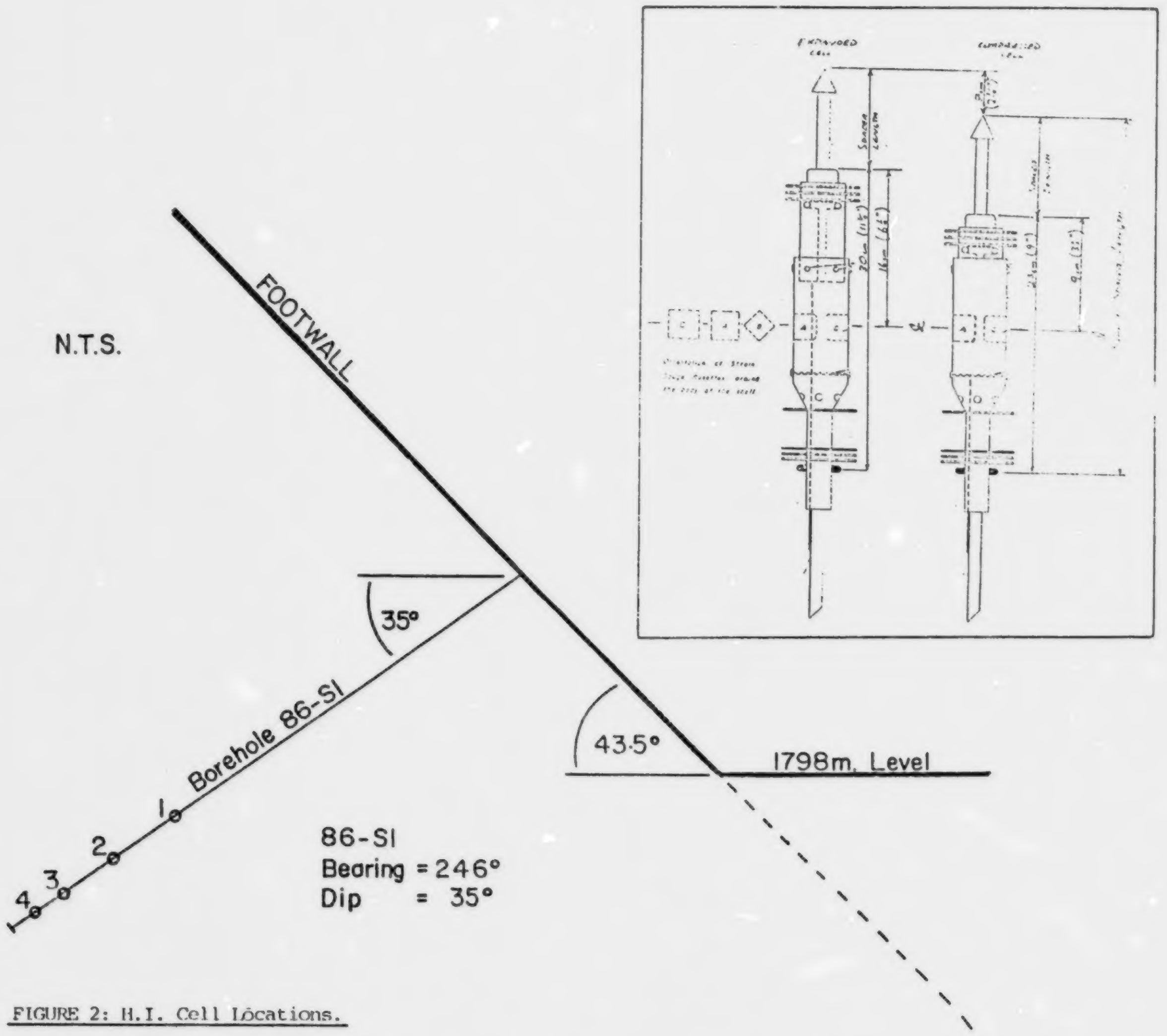
1. Shear stresses are not shown.
2. Parallel to sandstone footwall, down dip.
3. Normal to sandstone footwall.
4. Stresses are not sensitive to the omission of any of the measured strains.
5. Peak value of 87 microstrain used for gauge 9.
6. Combined data from 1.1 and 2.4.

Figures


Highwall
1810
1798
1798
1798
1810
1798
86-SI
Footwall
Diamond Hole Locations
LINE CREEK PIT LIMIT
1810
1810
1822
MAIN HAUL ROAD
1834
DUMP ENTRANCE
1846
1858
1870

FOOTWALL STUDY - DRILL HOLE LOCATION PLAN

FIGURE 1: Surface plan, Line Creek Mine



EXPANDED CELL
COMPRESSED CELL
SPACER LENGTH
16cm (6¼")
9cm (3½")
23cm (9")
N.T.S.
FOOTWALL
35°
Borehole 86-SI
1
2
3
4
43.5°
1798m. Level
86-SI
Bearing = 246°
Dip = 35°

FIGURE 2: H.I. Cell Locations.

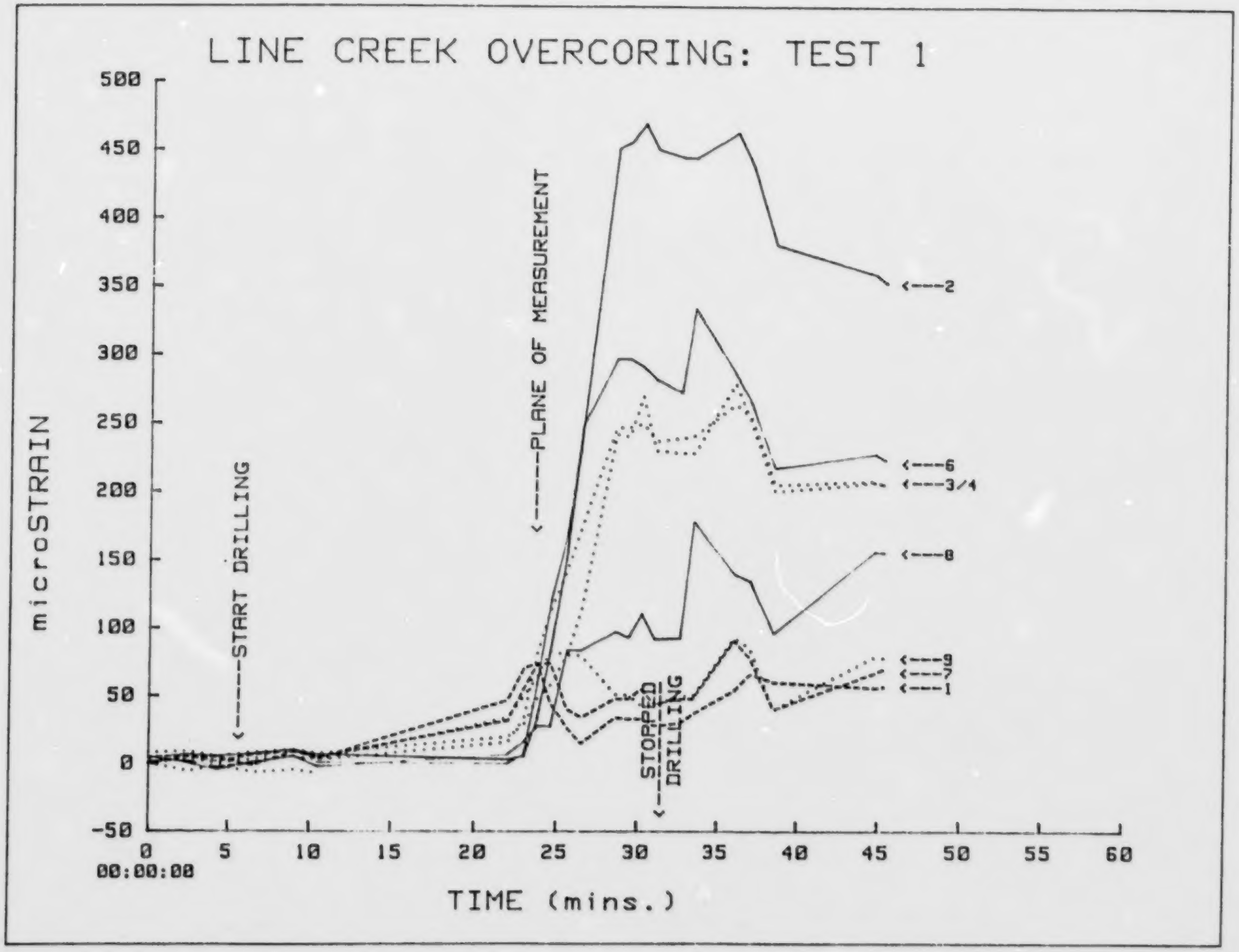


FIGURE 3: Overcore #1 Results

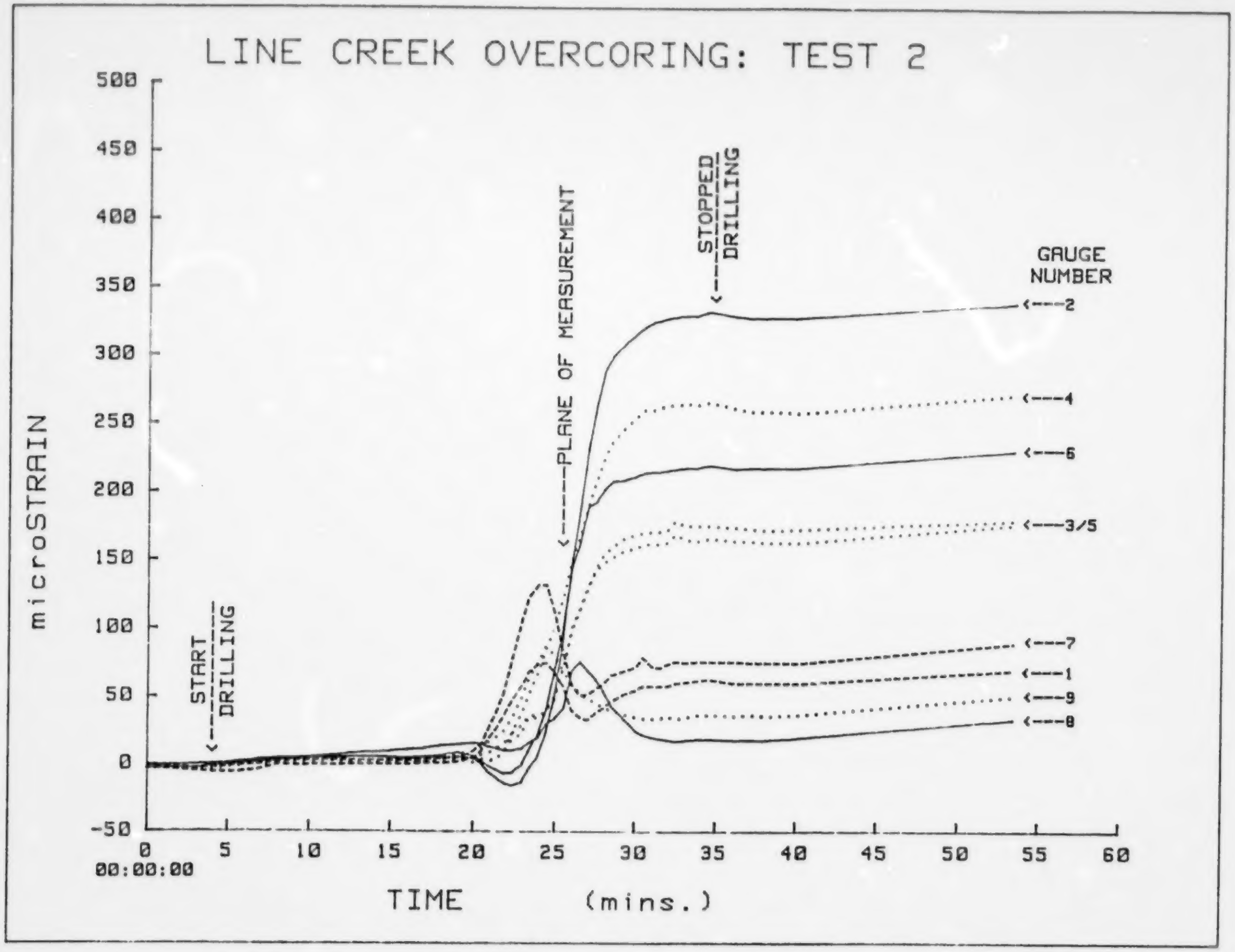


FIGURE 4: Overcore #2 Results

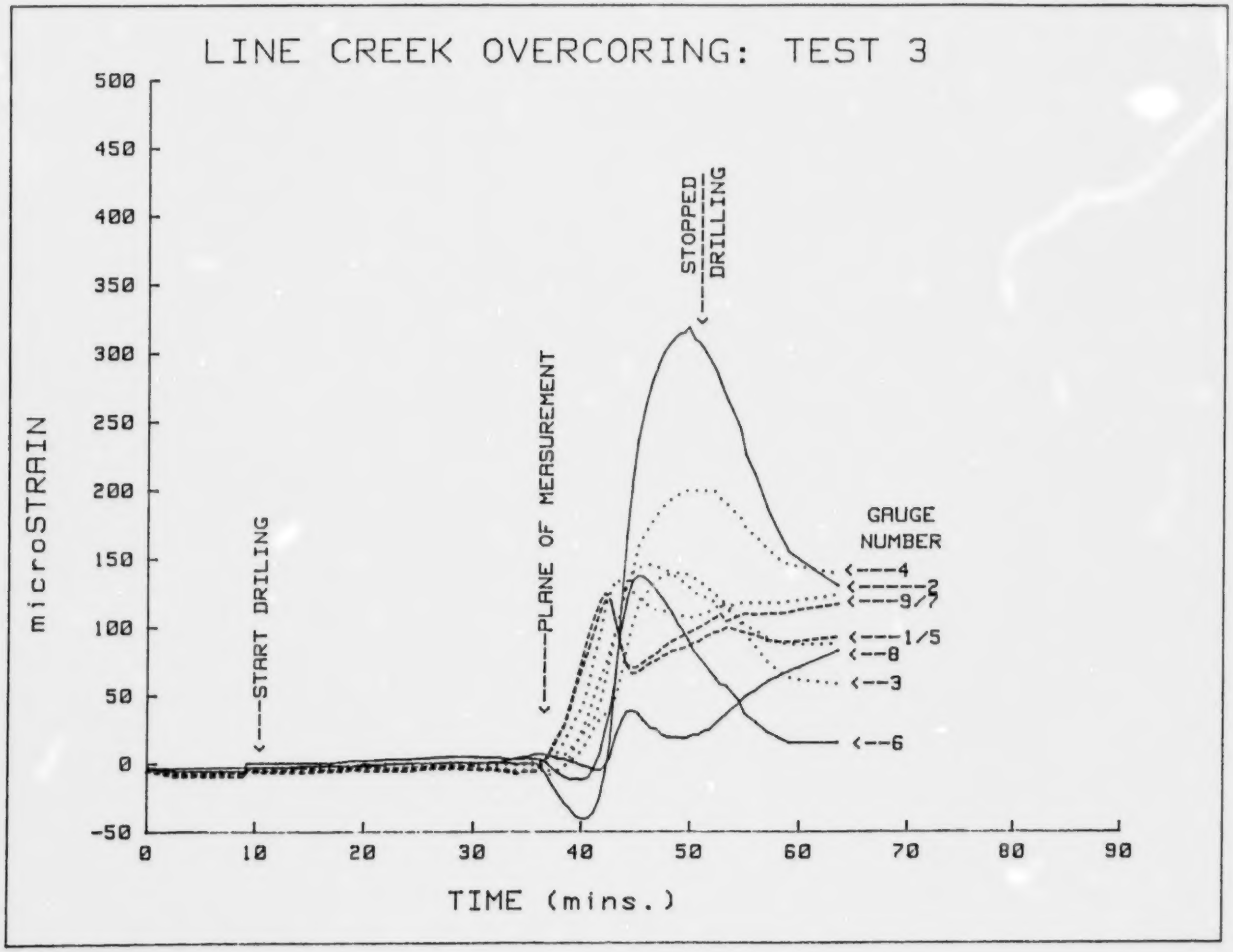


FIGURE 5: Overcore #3 Results

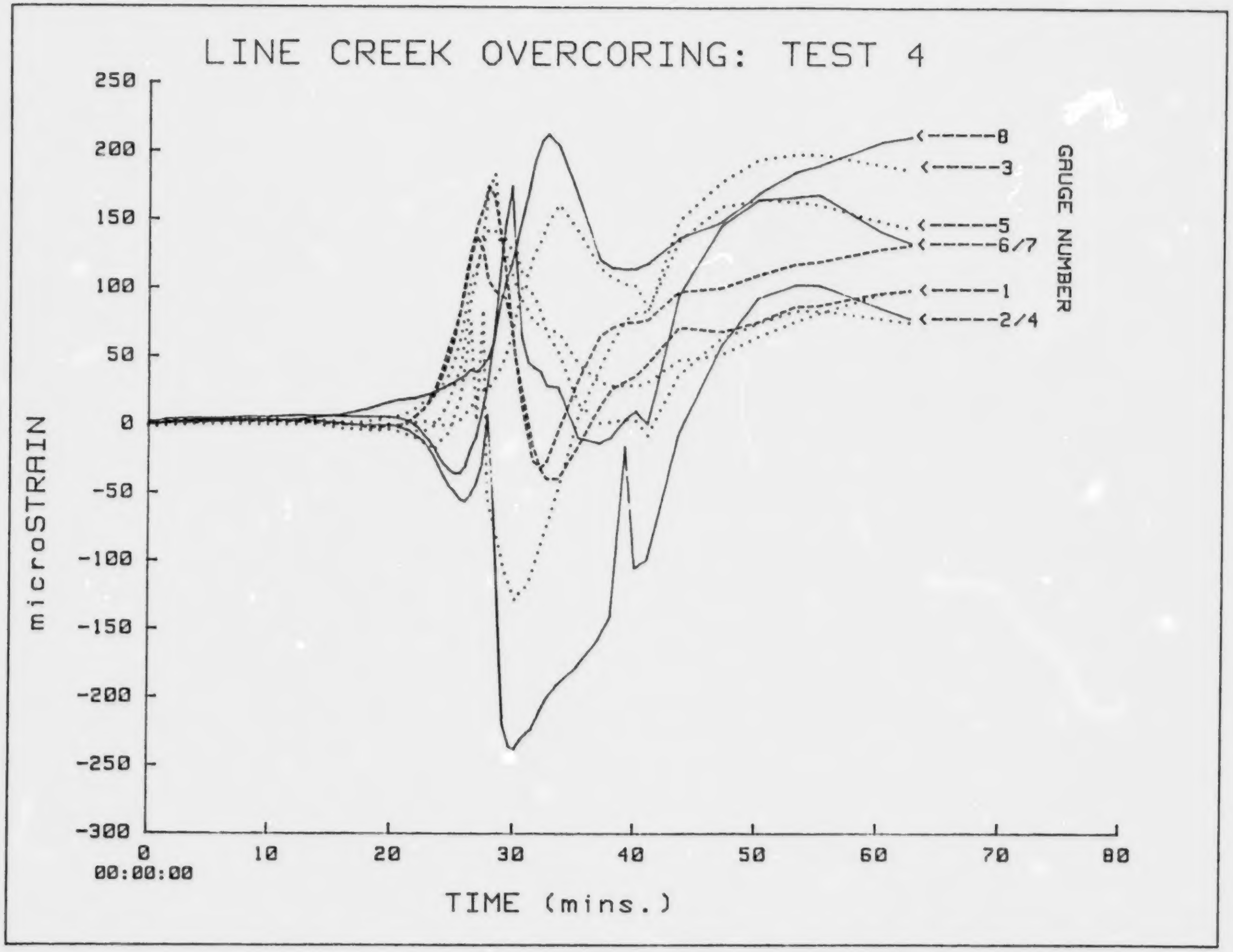


FIGURE 6: Overcore #4 Results

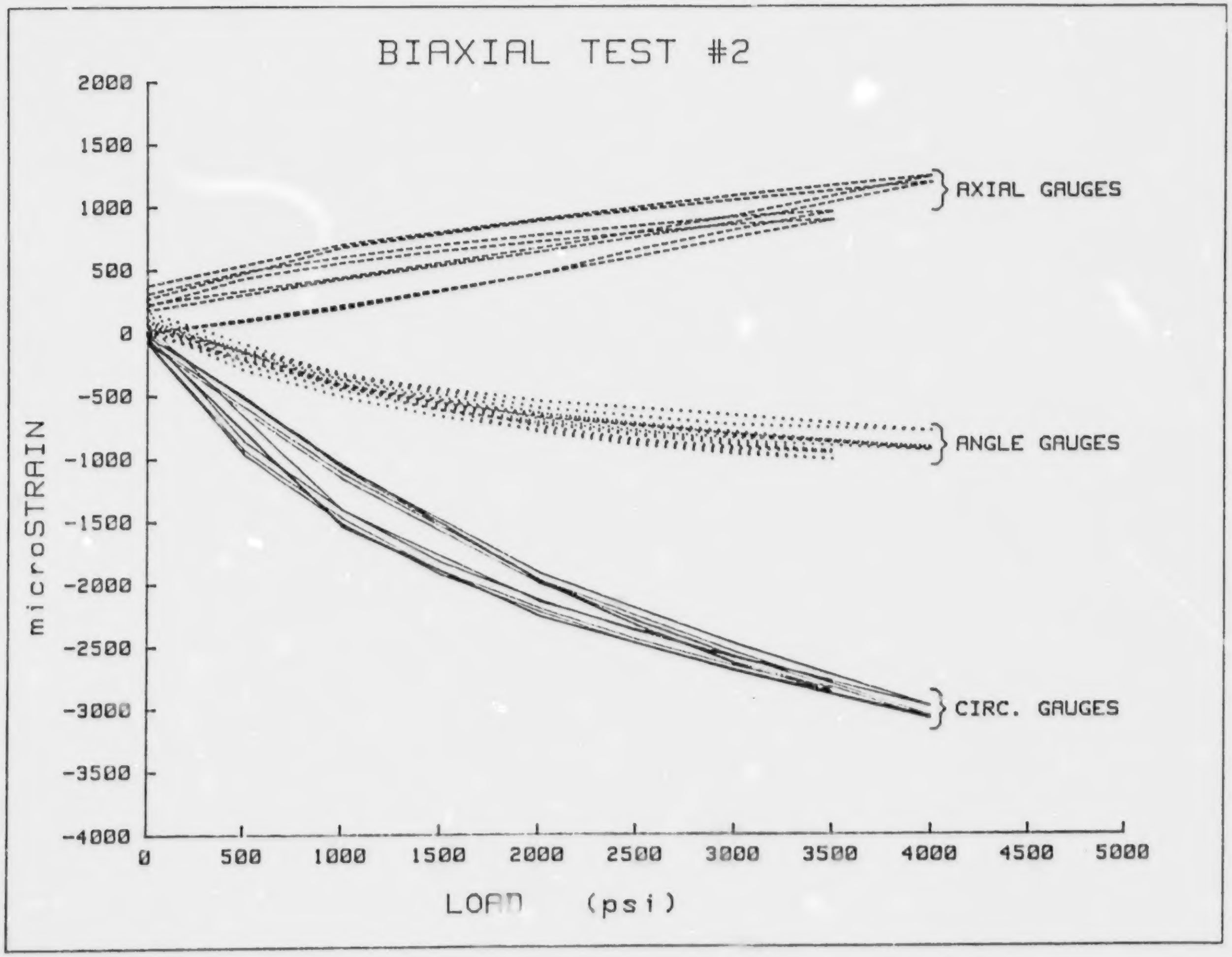


FIGURE 7: Biaxial Test #2 Results

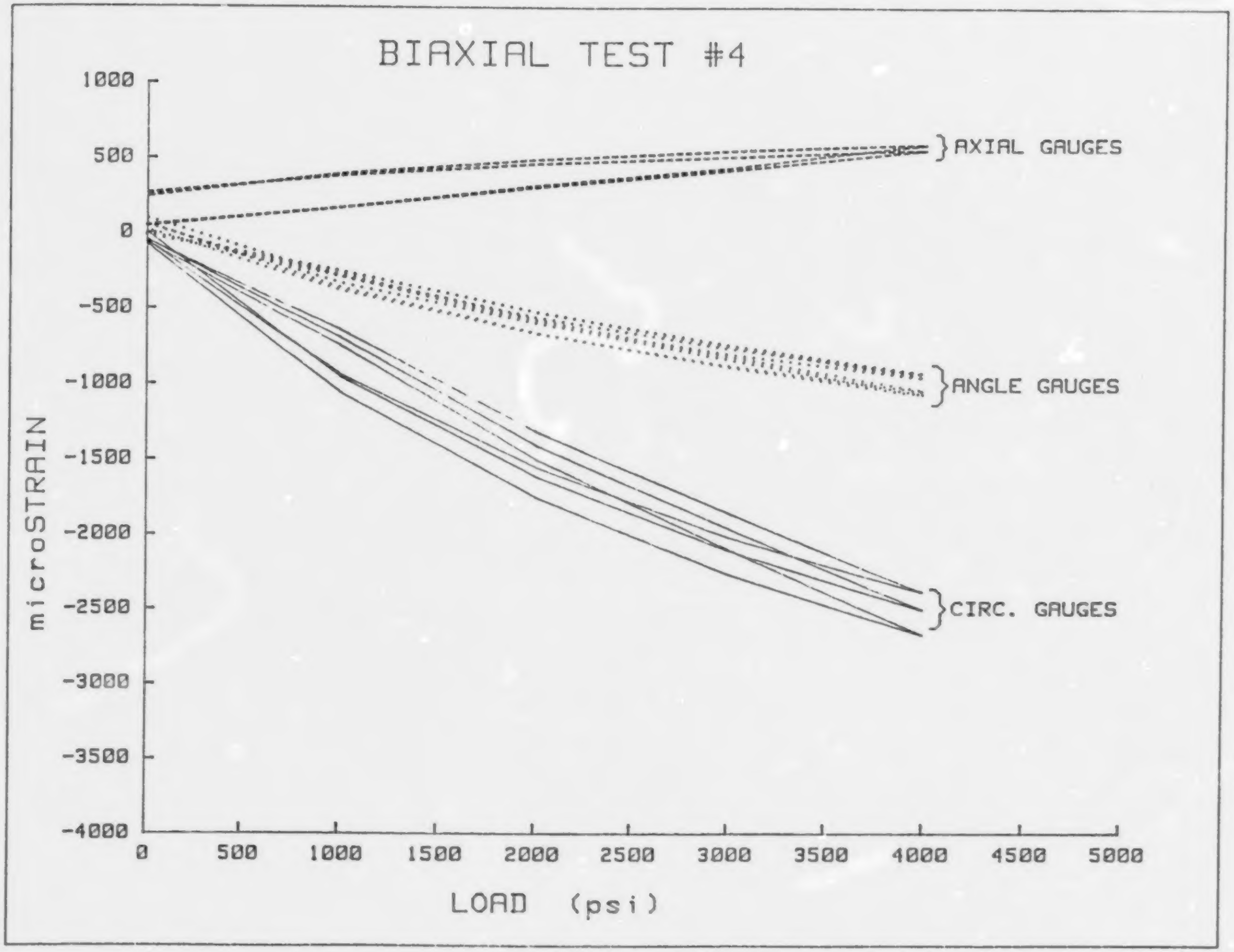


FIGURE 8: Biaxial Test #4 Results

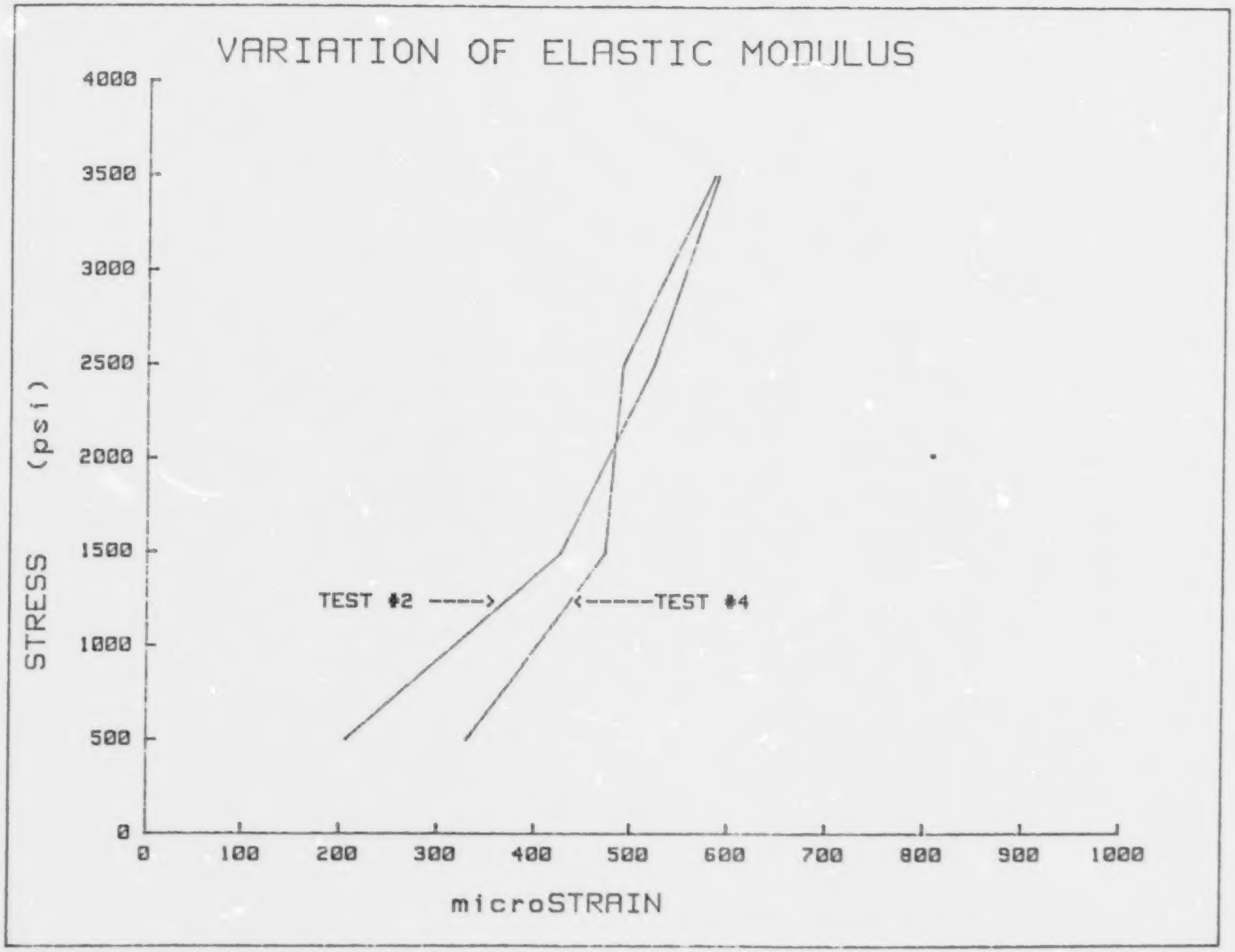


FIGURE 9: Variation of modulus with load

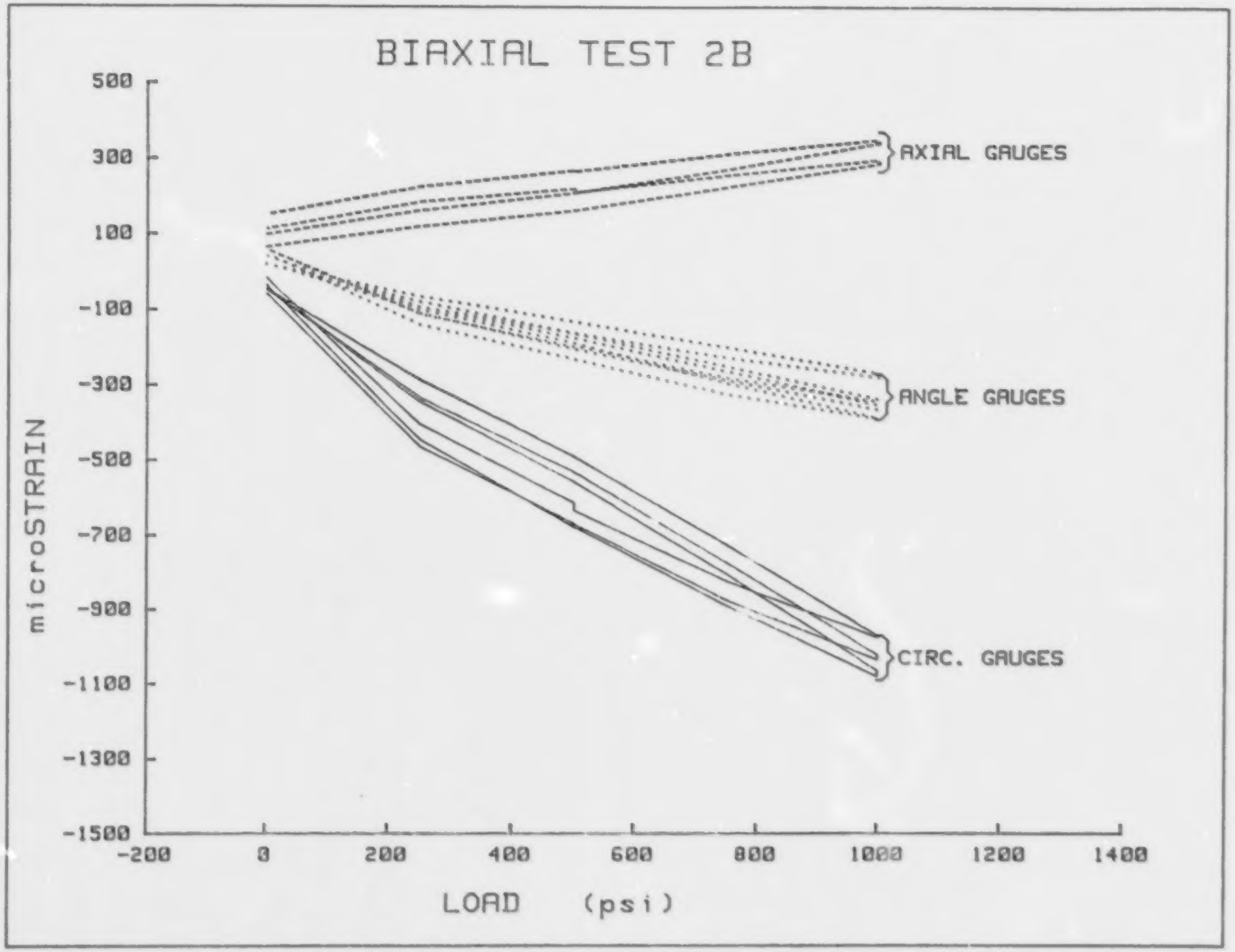


FIGURE 10: Biaxial Test #2B Results

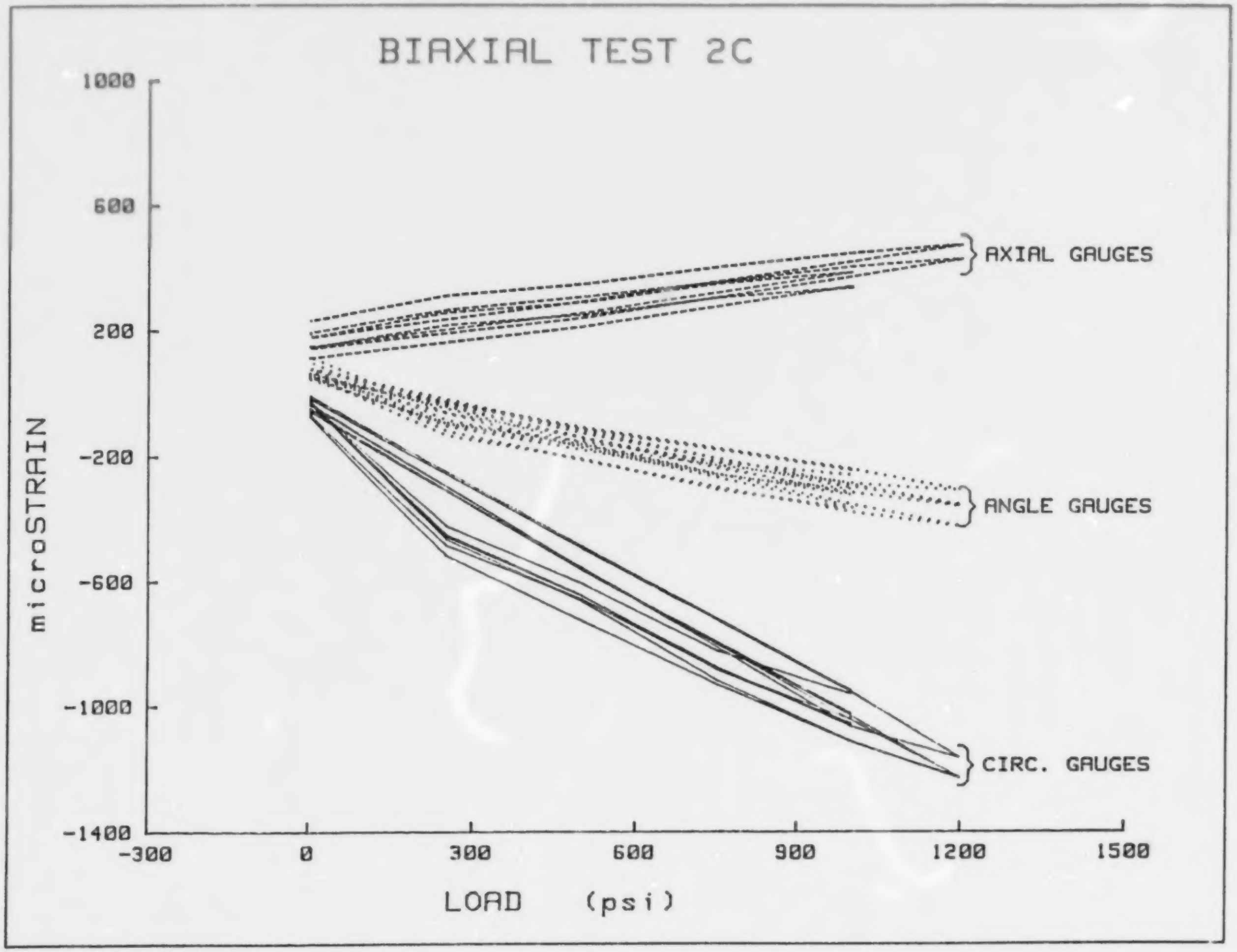


FIGURE 11: Biaxial Test #2C Results

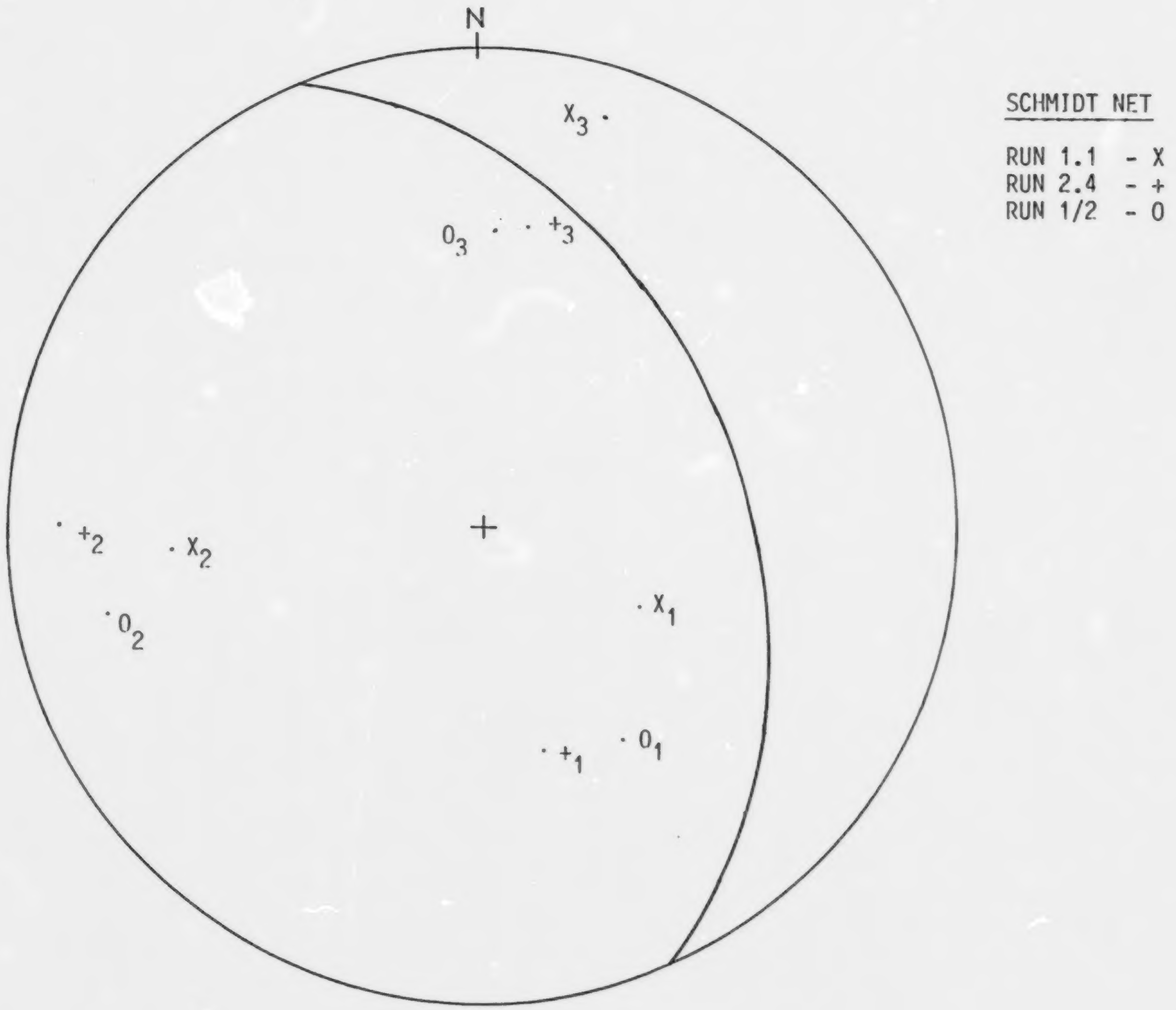


FIGURE 12: Principal Stress Directions

Plates

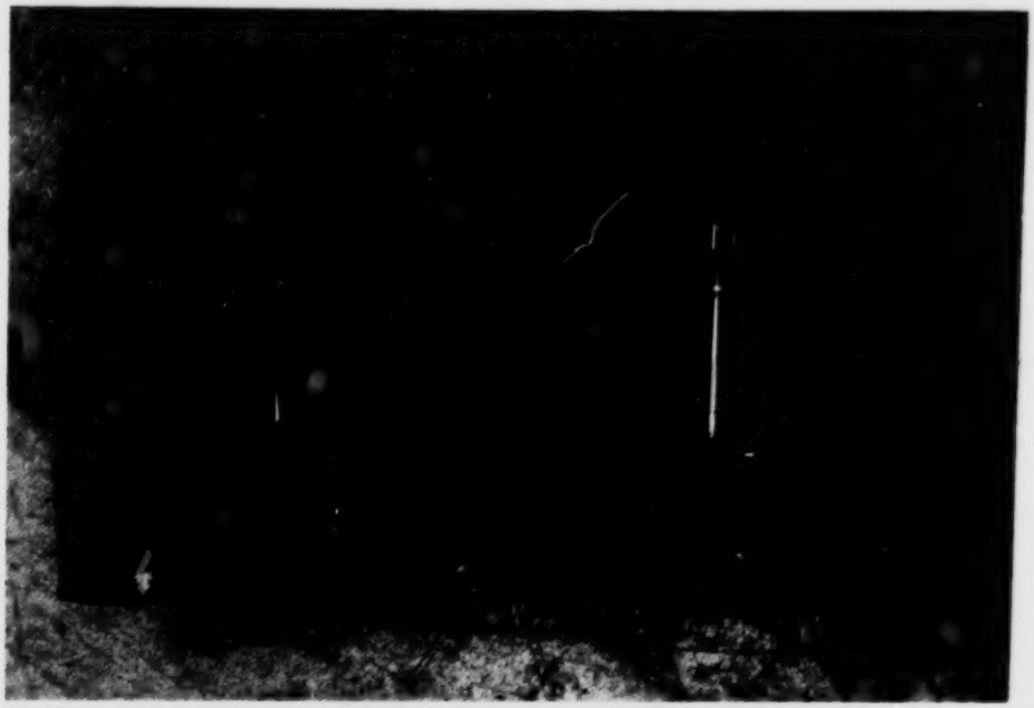


Plate 1 Section of Overcore #1

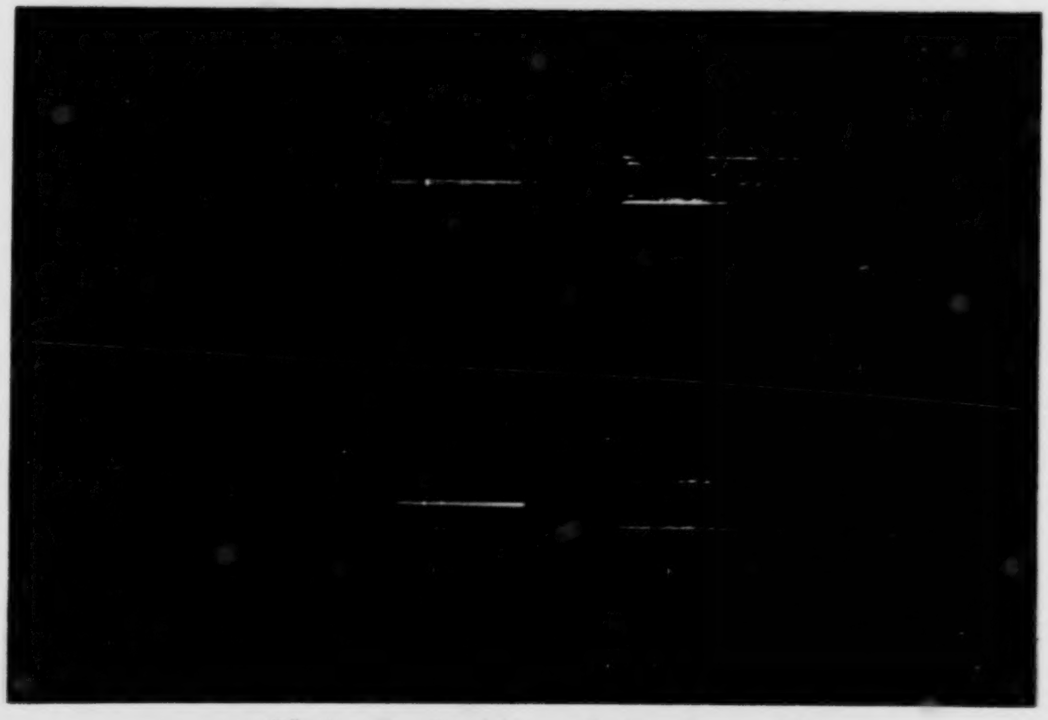


Plate 2 Section of Overcore #2

Appendix I

CSIRO H.I. CELL OVERCORE RESULTS

OVERCORE NO. 1

	TIME mins.	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	0	4	0	8	0	2	5	5	4
2	2.5	5	7	3	9	-6	2	5	0	5
3	4.3	4	5	-1	5	-2	-3	1	-5	0
4	6.5	-2	7	3	8	-7	1	6	0	3
5	9.0	8	10	5	10	-5	5	9	5	10
6	10.5	4	6	2	7	-8	0	3	-3	2
7	22.0	32	3	16	20	0	0	47	7	34
8	23.0	56	6	34	29	0	8	71	17	50
9	23.8	74	33	82	48	0	59	74	28	64
10	24.6	44	85	114	58	0	120	74	28	83
11	25.6	27	156	143	80	0	170	40	84	80
12	26.5	15	240	175	114	0	248	34	84	80
13	28.6	34	451	247	242	0	297	48	98	51
14	29.4	33	456	247	240	0	297	48	93	50
15	30.2	33	469	250	270	0	291	55	111	43
16	31.0	28	450	237	230	0	282	44	92	44
17	32.6	30	444	239	228	0	272	48	93	50
18	33.5	37	444	241	228	0	334	48	179	50
19	36.0	54	463	264	279	0	286	91	140	93
20	37.0	66	438	254	251	0	265	78	135	85
21	38.5	60	380	205	200	0	217	40	96	40
22	44.8	56	358	208	207	0	228	67	157	79
23	45.3	57	352	204	205	0	223	70	156	78

OVERCORE NO. 2

	TIME mins.	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	-3	-1	-3	-3	-3	-3	-1	-1	-3
2	3.0	-5	0	-4	-4	-4	-3	-3	0	-4
3	4.0	-6	0	-3	-4	-3	-1	-3	1	-2
4	5.3	-6	1	-2	-2	-2	0	-1	2	-2
5	6.9	-4	4	0	0	0	2	0	3	0
6	8.2	0	5	1	0	0	3	2	4	0
7	9.3	-1	5	2	2	1	4	3	5	1
8	10.3	0	6	2	2	2	5	3	6	2
9	11.3	-1	6	2	2	2	4	3	7	2
10	12.3	0	5	2	2	1	5	3	8	3
11	13.4	0	5	2	3	1	6	3	9	3
12	14.0	0	5	1	1	0	6	3	9	3
13	15.0	0	4	2	1	0	5	2	10	3
14	16.0	0	3	1	2	0	5	2	11	5
15	17.0	1	5	2	2	1	6	3	12	6
16	18.0	1	5	3	3	1	7	4	14	6
17	19.0	2	6	4	4	3	9	5	15	8
18	20.0	5	4	4	5	1	6	10	16	10
19	20.5	10	0	4	7	0	2	16	15	13
20	20.8	18	-5	3	8	2	-1	25	13	16
21	21.3	26	-10	3	12	4	-4	38	12	20
22	21.8	36	-14	9	15	9	-7	54	10	25
23	22.3	48	-16	18	23	23	-6	79	10	34
24	22.9	58	-13	23	38	29	0	107	12	50
25	23.3	68	-4	34	51	36	10	123	16	63
26	23.9	74	6	35	67	37	23	132	20	75
27	24.4	75	23	39	85	39	40	132	30	87
28	24.9	68	49	50	100	47	68	112	34	81
29	25.5	57	94	72	124	72	104	81	42	69
30	26.0	40	148	98	151	101	145	59	69	58
31	26.5	35	187	113	168	115	163	51	76	54
32	27.0	33	231	128	190	131	189	52	69	48
33	27.5	38	263	144	208	142	193	56	63	46
34	28.0	42	289	154	225	148	202	60	54	42
35	28.5	47	300	160	237	152	208	66	43	40
36	29.2	52	309	166	247	157	209	69	34	37
37	30.0	55	317	169	255	159	212	72	25	35
38	30.4	58	321	170	260	162	214	79	22	34
39	31.0	58	325	171	260	162	215	72	20	34
40	31.4	58	326	171	262	162	215	71	19	34
41	31.9	58	328	172	264	163	216	74	18	36
42	32.4	60	329	179	264	169	217	76	17	34
43	33.0	61	330	175	265	165	218	75	18	35
44	33.8	62	330	175	264	164	218	76	19	37
45	34.5	63	333	175	266	166	220	76	19	37
46	36.2	60	329	174	261	164	217	76	18	36
47	37.0	60	328	173	259	164	218	75	18	37
48	38.0	60	328	172	259	163	218	75	18	36
49	40.0	60	328	173	258	163	218	75	20	37
50	53.4	70	339	180	272	177	231	90	34	51

OVERCORE NO. 3

	TIME mins.	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	-6	-4	-5	-5	-6	-3	-5	-5	-5
2	2.5	-8	-6	-9	-6	-9	-4	-10	-6	-8
3	9.1	-7	-6	-8	-6	-8	-3	-10	-6	-7
4	9.3	-4	-3	-5	-3	-5	0	-6	-3	-4
5	10.3	-6	-3	-6	-3	-6	0	-7	-4	-5
6	12.0	-5	-3	-6	-3	-6	0	-7	-3	-5
7	13.0	-5	-3	-6	-3	-6	0	-7	-3	-5
8	14.0	-4	-2	-5	-2	-5	0	-7	-3	-4
9	15.0	-4	-2	-6	-3	-4	0	-7	-2	-5
10	16.0	-5	-2	-6	-2	-5	0	-6	-3	-5
11	17.0	-5	-2	-6	-2	-5	0	-6	-2	-4
12	18.0	-4	-2	-5	-2	-5	1	-6	-2	-4
13	19.0	-3	-2	-4	-1	-4	2	-5	-2	-3
14	20.0	-3	0	-4	-1	-4	2	-6	-2	-3
15	21.0	-3	-1	-5	-2	-5	2	-6	-2	-3
16	22.0	-4	-1	-4	0	-4	3	-6	-1	-3
17	24.0	-3	0	-4	-1	-4	3	-6	0	-3
18	26.0	-2	0	-3	0	-2	4	-4	0	-3
19	28.0	-2	1	-3	1	-2	5	-4	0	-1
20	30.0	-2	1	-2	0	-3	5	-5	0	-2
21	31.0	-5	0	-4	0	-3	4	-5	0	-2
22	31.5	-3	0	-3	0	-3	4	-5	1	-1
23	32.0	-5	0	-4	0	-3	4	-5	1	-2
24	32.5	-5	0	-4	0	-4	4	-6	1	-1
25	33.0	-5	0	-5	0	-4	3	-6	2	-1
26	33.5	-5	0	-5	0	-5	3	-7	3	0
27	34.0	-7	-1	-5	-2	-6	3	-8	4	0
28	34.5	-6	0	-5	-2	-5	3	-6	5	0
29	35.0	-5	0	-4	0	-5	4	-6	5	1
30	35.3	-6	0	-5	-2	-5	3	-6	6	0
31	35.8	-5	0	-5	-2	-5	3	-6	7	3
32	36.3	0	-3	-3	2	-5	2	-2	7	3
33	36.8	4	-9	-6	4	-8	0	5	6	4
34	37.3	13	-16	-4	4	-9	-4	10	5	6
35	37.8	20	-22	-5	6	-6	-7	18	3	8
36	38.4	27	-29	-2	6	-3	-10	28	3	15
37	39.0	41	-34	2	10	5	-12	44	1	25
38	39.5	56	-39	5	15	13	-11	60	0	33
39	40.1	70	-41	10	20	24	-12	78	-2	41
40	40.7	85	-40	18	28	36	-10	96	-3	58
41	41.2	98	-36	26	33	49	-3	108	-5	78
42	41.7	113	-24	33	45	63	8	120	-5	96
43	42.2	120	-8	36	60	71	23	125	-2	114
44	42.7	119	16	40	78	85	40	119	5	126
45	43.2	102	62	49	98	98	65	103	20	135
46	43.7	85	113	65	115	115	99	87	30	132
47	44.2	72	166	85	134	128	120	73	38	128
48	44.7	66	205	102	141	140	134	70	39	126
49	45.2	67	237	115	159	144	138	71	37	122
50	45.7	70	257	122	167	145	137	74	32	118
51	46.3	74	278	130	176	146	132	78	26	115
52	46.9	76	290	135	183	144	126	81	25	112
53	47.4	79	300	138	188	143	121	85	21	112
54	47.9	81	306	139	192	141	115	88	19	111
55	48.3	83	310	140	195	139	110	90	19	109

56	48.8	84	314	140	197	135	102	92	19	108
57	49.3	85	315	140	200	133	97	94	18	108
58	49.7	86	319	138	200	130	91	96	19	107
59	50.2	89	310	136	200	126	83	98	21	107
60	50.8	90	307	134	200	123	78	100	21	109
61	51.2	93	301	130	200	122	73	102	24	110
62	51.7	95	294	127	199	120	68	105	25	112
63	52.2	97	287	124	199	118	63	107	29	114
64	52.7	97	278	120	194	115	58	110	32	118
65	53.2	100	267	117	190	113	57	104	36	115
66	54.5	97	245	104	180	106	45	109	45	118
67	55.0	96	226	95	173	101	36	110	49	118
68	56.0	94	209	85	166	97	30	109	54	118
69	57.0	90	187	75	157	92	23	110	60	118
70	58.0	89	170	68	150	89	19	110	64	118
71	59.0	89	155	63	145	87	15	111	68	119
72	60.0	90	149	61	144	87	15	113	71	120
73	63.5	93	130	58	139	88	15	117	83	124

OVERCORE NO. 4

	TIME mins.	GAUGE READINGS microSTRAIN 1	2	3	4	5	6	7	8	9
1	0.0	0	0	0	0	1	2	0	0	-2
2	.8	0	0	0	0	1	2	0	0	-2
3	1.5	2	2	0	2	3	4	1	1	-1
4	4.0	3	3	2	2	3	5	1	2	0
5	6.0	3	4	2	3	4	5	3	2	0
6	8.0	3	4	2	3	4	6	2	3	0
7	10.0	3	4	3	3	4	6	2	3	0
8	12.0	4	3	1	4	4	7	2	4	0
9	14.0	2	3	0	4	2	7	1	6	2
10	16.0	0	1	-3	2	0	6	0	8	1
11	17.0	0	0	-3	2	0	6	0	10	2
12	18.0	-1	0	-4	0	0	6	-2	12	3
13	19.0	0	0	-4	0	-1	6	-2	15	4
14	19.8	0	0	-3	1	-1	6	0	17	6
15	20.6	0	-1	-5	0	-2	5	0	19	7
16	21.0	2	-3	-6	0	-3	4	1	19	8
17	21.4	3	-4	-8	2	-4	3	3	20	10
18	21.8	6	-7	-9	2	-4	0	6	20	12
19	22.2	9	-9	-11	3	-5	-2	9	21	14
20	22.6	12	-12	-13	3	-4	-7	12	22	17
21	23.0	18	-17	-13	3	-3	-11	17	23	20
22	23.4	25	-23	-19	2	0	-16	22	25	22
23	23.8	33	-29	-13	0	3	-22	30	26	26
24	24.2	45	-37	-9	0	10	-28	39	28	31
25	24.6	58	-44	-5	0	18	-32	50	30	37
26	25.0	69	-48	6	2	29	-35	63	32	47
27	25.5	84	-54	20	4	42	-35	84	35	63
28	25.9	102	-56	45	8	66	-30	108	37	83
29	26.3	123	-51	75	13	92	-18	128	41	107
30	26.8	139	-42	3	20	113	-8	146	39	117
31	27.3	128	-27	85	26	142	12	160	44	134
32	27.8	106	8	-53	26	170	30	175	49	143
33	28.3	99	-58	-73	33	184	65	167	62	143
34	28.7	95	-133	-86	40	145	103	146	85	134
35	29.2	93	-220	-107	50	136	147	115	104	125
36	29.7	74	-236	-119	65	128	175	78	118	112
37	30.1	46	-238	-129	83	126	118	45	135	99
38	30.6	25	-231	-121	104	109	63	14	154	90
39	31.1	4	-226	-118	99	110	46	-8	172	83
40	31.5	-14	-223	-107	95	125	43	-26	191	76
41	32.2	-32	-211	-88	82	136	39	-31	208	72
42	32.7	-39	-202	-74	67	148	29	-26	213	70
43	33.6	-39	-191	-47	54	162	28	-4	204	68
44	35.2	-15	-177	7	16	141	-9	34	166	45
45	37.0	14	-157	43	2	115	-13	66	121	32
46	38.0	27	-140	61	3	108	-8	72	115	29
47	39.2	33	-15	78	5	103	5	76	114	30
48	40.0	37	-105	83	4	102	11	76	115	29
49	41.0	46	-98	84	-7	85	1	78	119	32
50	43.5	72	-7	150	37	135	95	98	137	48
51	47.0	69	58	178	64	160	146	101	149	52
52	50.0	76	93	194	75	165	165	110	169	65
53	53.0	87	103	195	84	163	167	118	185	76
54	55.0	88	103	198	84	161	169	120	190	82
55	60.0	97	86	190	78	149	142	129	207	96
56	62.5	99	78	186	75	144	133	132	211	99

Appendix II

CSIRO H.I. CELL BIAXIAL TEST RESULTS

BIAXIAL TEST NO. 2

	LOAD psi	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	12	-22	-5	-6	-5	-22	5	-21	-8
2	500.0	92	-517	-215	-207	-197	-505	106	-507	-191
3	1000.0	196	-1069	-433	-430	-408	-1044	221	-1048	-396
4	2000.0	469	-1976	-751	-793	-714	-1972	467	-1960	-742
5	2500.0	660	-2333	-854	-894	-787	-2322	603	-2296	-852
6	3000.0	818	-2644	-911	-967	-843	-2626	757	-2582	-923
7	3500.0	960	-2865	-942	-1007	-858	-2840	896	-2773	-956
8	3000.0	915	-2681	-870	-936	-786	-2654	854	-2590	-892
9	2500.0	845	-2467	-802	-864	-715	-2435	791	-2370	-816
10	2000.0	774	-2210	-713	-773	-640	-2181	722	-2114	-723
11	1500.0	696	-1915	-609	-663	-546	-1881	647	-1814	-613
12	1000.0	600	-1503	-455	-507	-410	-1465	554	-1397	-454
13	500.0	485	-959	-246	-295	-222	-924	431	-855	-250
14	0.0	307	-76	102	47	96	-63	211	10	59
15	0.0	230	-74	63	40	69	-55	180	7	47
16	1000.0	445	-1154	-365	-374	-323	-1111	430	-1055	-338
17	2000.0	675	-1990	-666	-689	-600	-1958	645	-1905	-642
18	3000.0	927	-2575	-827	-862	-735	-2544	877	-2477	-815
19	4000.0	1245	-3082	-925	-936	-781	-3061	1196	-2980	-911
20	3000.0	1085	-2694	-804	-800	-654	-2691	1050	-2580	-797
21	2000.0	900	-2245	-672	-670	-542	-2246	888	-2127	-660
22	1000.0	700	-1535	-432	-433	-342	-1515	677	-1400	-412
23	0.0	371	-33	147	115	174	-27	270	79	106
24	0.0	275	-18	106	116	146	-14	234	84	97
25	0.0	243	-11	85	113	130	-2	211	86	90
26	0.0	215	-4	77	105	120	7	194	89	84

BIAXIAL TEST NO. 4

	LOAD psi	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	50	-66	-14	-11	-18	-49	47	-47	-9
2	0.0	52	-64	-11	-8	-15	-46	45	-46	-5
3	1000.0	175	-745	-284	-248	-271	-641	175	-693	-252
4	2000.0	314	-1497	-590	-521	-572	-1314	326	-1405	-521
5	3000.0	430	-2094	-835	-743	-814	-1852	449	-1955	-736
6	4000.0	560	-2669	-1065	-953	-1040	-2380	596	-2500	-928
7	3000.0	516	-2258	-880	-793	-872	-2010	555	-2099	-757
8	2000.0	466	-1747	-657	-593	-661	-1547	493	-1609	-553
9	1000.0	384	-1054	-358	-327	-377	-933	398	-950	-284
10	0.0	262	-73	62	55	24	-55	239	7	100
11	0.0	243	-63	54	58	31	-46	228	2	93
12	0.0	236	-58	50	58	36	-42	223	-2	90

BIAXIAL TEST NO. 2B

	LOAD psi	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	66	-47	22	19	20	-46	99	-48	20
2	250.0	120	-334	-102	-66	-80	-286	163	-344	-95
3	500.0	163	-531	-189	-133	-164	-490	210	-557	-176
4	750.0	225	-773	-295	-200	-251	-725	272	-804	-264
5	1000.0	286	-1022	-388	-270	-338	-970	341	-1064	-353
6	1000.0	295	-1034	-388	-279	-343	-974	348	-1079	-364
7	750.0	255	-873	-323	-226	-280	-822	311	-888	-28[illegible]
8	500.0	210	-668	-231	-161	-195	-632	265	-675	-203
9	500.0	220	-667	-230	-160	-198	-612	268	-677	-203
10	250.0	184	-463	-140	-93	-112	-403	224	-444	-110
11	0.0	113	-58	47	42	59	-17	151	-36	59

BIAXIAL TEST NO. 2C

	LOAD psi	GAUGE READINGS microSTRAIN								
		1	2	3	4	5	6	7	8	9
1	0.0	114	-48	50	50	65	-7	151	-35	60
2	500.0	215	-562	-172	-112	-139	-486	260	-555	-141
3	1000.0	344	-1022	-360	-243	-300	-950	388	-1065	-320
4	1000.0	337	-1042	-364	-257	-303	-960	387	-1053	-320
5	750.0	306	-880	-303	-216	-256	-821	350	-880	-254
6	500.0	250	-655	-206	-150	-177	-604	291	-644	-164
7	250.0	217	-480	-131	-93	-102	-418	257	-452	-91
8	0.0	145	-65	61	46	73	-22	178	-30	80
9	0.0	144	-56	64	52	78	-14	179	-28	81
10	500.0	243	-562	-157	-107	-126	-493	296	-557	-117
11	1000.0	374	-1030	-352	-240	-288	-953	422	-1043	-294
12	1200.0	430	-1230	-420	-305	-352	-1164	475	-1228	-356
13	1000.0	404	-1111	-375	-283	-313	-1062	447	-1109	-311
14	750.0	354	-928	-295	-225	-255	-873	402	-915	-236
15	500.0	308	-724	-210	-165	-160	-643	348	-661	-138
16	250.0	266	-513	-117	-96	-83	-444	311	-461	-60
17	0.0	193	-72	85	52	102	-23	230	-22	117
18	0.0	190	-65	87	63	109	-13	232	-21	118

APPENDIX B

DETAILS OF COMPUTER PROGRAM "CURVBUK" - COMPREHENSIVE ANALYSIS OF BUCKLING OF CURVED SLABS

B.1 INTRODUCTION

Program CURVBUK is a user friendly program written in Turbo Pascal version 3.0 which analyzes curved slopes using 3 hinged buckling methods. This appendix presents the equations used in program CURVBUK and a general outline of the method of analysis. A listing of CURVBUK.PAS is attached to the end of this appendix.

To run program CURVBUK, the following system resources are required:

- IBM PC or close clone with a minimum of 128 K.
- 80 column printer.
- Turbo Pascal version 3.0 or 3.1 only if changes to the program are desired.

The compiled version of the program is CURVBUK.COM. To run the program, type CURVBUK and follow the instructions given. Variables are defined below.

B.2 METHOD OF ANALYSIS USED IN CURVBUK

The general method of analysis for 3 hinged buckling of a curved slope is outlined in Cavers (1981). The equations shown in Cavers (1981) have been simplified and the matrix partitioned to a 4X4 matrix.

Figure B-1 shows the general block arrangement on the slope. Hinge points for the rotation of the blocks are at points A, B and C. Each block is examined for stability in X and Y directions and moments, yielding three equations for each block for a total of six equations. The matrix is then partitioned by back substituting moment arms for shear normal forces on the ends of the blocks in the moment equations. This yields a 4X4 matrix which may be inverted to find the forces on the ends of the blocks. Figure B-2 shows derivation of the equations.

Program CURVBUK also applies a perturbing force to the hinge point B to assess whether the slope is stable, conditionally stable or unstable. The results of these calculations are summarized in Section 4.3.2.3.

The program analyzes a curved slope using three possible modes. These modes are shown schematically on Figures B-3a to B-3c and are discussed briefly below:

a) MODE 1: This mode assumes a circular roll in which both blocks are on the circular part of the roll. Analysis has shown that for many cases, this mode is not the critical mode of failure and Mode 3 should be used in preference. In Mode 1, many of the variables are calculated automatically, reducing the amount of data entry.

b) MODE 2: This mode is completely general and allows explicit input of all variables describing the roll. The variables are not calculated and thus the input is slightly more tedious.

c) MODE 3: Mode 3 is similar to Mode 1 except block 1 is on the plane portion of the slope and block 2 is on the circular curved portion of the slope. As with Mode 1, many of the calculations are done automatically. Mode 3 is accessible only from Method 2 (see below).

Two methods of data input are possible:

a) METHOD 1: The program asks for the data in a question/answer format. This method of data input was used during early development of the program, prior to the development of Method 2 which is the preferred method of data input.

b) METHOD 2: This method of data input allows full screen editing of all variables and supports calculation of the variables where the mode allows it. The general input screen is shown on Figure 4-12. This is the preferred method of data entry since multiple runs can be made very quickly.

The program allows data to be saved to disk at any time. This facility was principally developed for use in Method 1, and has not being used extensively in Method 2 since data entry is so quick using the full screen editing. Therefore, caution should be used when saving data to disk in Method 2.

Interpretation of the results is briefly discussed in Section 4.3.2. The results from the program should be interpreted by qualified personnel, and Hardy Associates and the authors of the program can take no responsibility for application of the program, or the ideas or equations within the programs to an individual users problem.

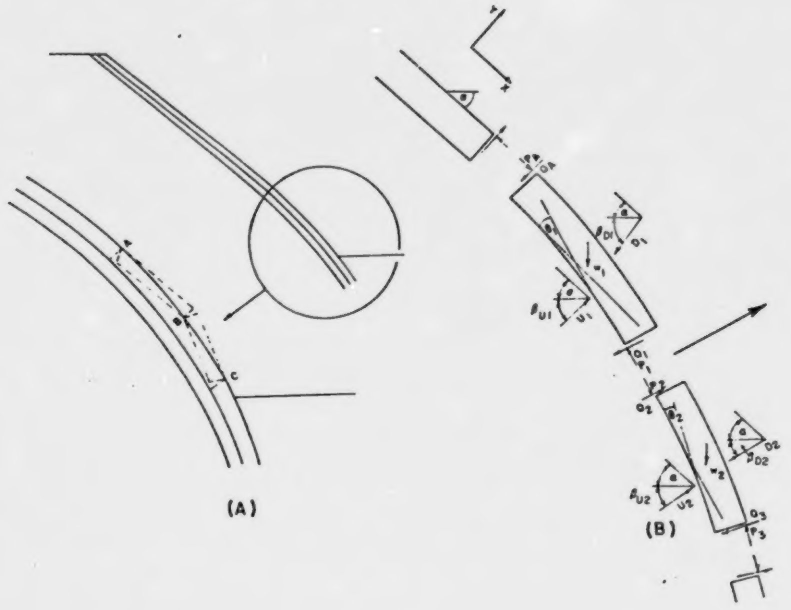


FIGURE B-1 General configuration analysed by Program 'CURVBUK' after Cavers (1981). The arrangement of failing blocks is shown on (A). The blocks are subject to weight forces (W_1 and W_2), water pressure forces (U_1 and U_2) and external forces (D_1 and D_2). The blocks are assumed to rotate about points A,B and C. The program also applies a perturbing force at point B to check stability modes.

P_A	Normal force on upper hinge of block 1.
P_1, P_2, P_3	Normal forces acting on block hinge points.
Q_A	Shear force corresponding to P_A.
Q_1, Q_2, Q_3	Shear forces acting on block hinge points.
W_1, W_2	Weight of block 1 or 2.
D_1, D_2	External forces applied to blocks 1 and 2.
U_1, U_2	Water pressure forces.
X_{W1B} etc.	Moment arms of force about stated point (here the moment arm of W_1 about point B).
β_{U1} etc.	Angle between horizontal and named force (here U_1)
Θ_1, Θ_2	Curvature of blocks 1 and 2.
$\propto$	Dip of slope.

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FIGURE B-1

PROGRAM "CURVBUK"
GENERAL BLOCK ARRANGEMENT

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BLOCK 1:

EQUILIBRIUM IN THE X DIRECTION:

$$-P_1\cos\Theta_1 - Q_1\sin\Theta_1 + P_A + W_1\sin\alpha - D_1\cos(\beta_{D1}+\alpha) + U_1\cos(\beta_{U1}+\alpha) = 0 \qquad (1)$$

EQUILIBRIUM IN THE Y DIRECTION:

$$P_1\sin\Theta_1 - Q_1\cos\Theta_1 - Q_A - W_1\cos\alpha - D_1\sin(\beta_{D1}+\alpha) + U_1\sin(\beta_{U1}+\alpha) = 0 \qquad (2)$$

MOMENT EQUILIBRIUM ABOUT B:

$$-P_A X_{PAB} + Q_A X_{QAB} + W_1 X_{W1B} + D_1 X_{D1B} - U_1 X_{U1B} = 0 \qquad (3)$$

BLOCK 2

EQUILIBRIUM IN THE X DIRECTION

$$\begin{aligned} &P_2\cos\Theta_1 + Q_2\sin\Theta_1 - P_3\cos(\Theta_1+\Theta_2) - Q_3\sin(\Theta_1+\Theta_2) \\ &+W_2\sin\alpha - D_2\cos(\beta_{D2}+\alpha) + U_2\cos(\beta_{U2}+\alpha) = 0 \qquad (4) \end{aligned}$$

EQUILIBRIUM IN THE Y DIRECTION

$$\begin{aligned} &-P_2\sin\Theta_1 + Q_2\cos\Theta_1 + P_3\sin(\Theta_1+\Theta_2) - Q_3\cos(\Theta_1+\Theta_2) \\ &-W_2\cos\alpha - D_2\sin(\beta_{D2}+\alpha) + U_2\sin(\beta_{U2}+\alpha) = 0 \qquad (5) \end{aligned}$$

MOMENT EQUILIBRIUM ABOUT B:

$$P_3 X_{P3B} - Q_3 X_{Q3B} - W_2 X_{W2B} - D_2 X_{D2B} + U_2 X_{U2B} = 0 \qquad (6)$$

BY SYMMETRY:

$$P_1 = P_2 \qquad (7)$$

$$Q_1 = Q_2 \qquad (8)$$

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FIGURE B-2

PROGRAM "CURVBUK"
DERIVATION OF EQUATIONS

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SUBSTITUTING EQS. (7) AND (8), REARRANGING AND EXPRESSING IN MATRIX FORM YIELDS :

$$[A]\begin{Bmatrix} P_1 \\ Q_1 \\ P_A \\ Q_A \\ P_3 \\ Q_3 \end{Bmatrix} = \{B\} \qquad (9)$$

[A] MAY BE SIMPLIFIED FOR INVERSION BY SUBSTITUTING EQS. (3) AND (6) INTO EQS. (2), (4) AND (5)

SOLVING EQ.(3) IN TERMS OF Q_A YIELDS:

$$-X_{PAB}P_A + X_{QAB}Q_A = B_3 \quad \text{OR} \quad Q_A = \frac{B_3 + X_{PAB}P_A}{X_{QAB}} \qquad (10)$$

SOLVING EQ(6) IN TERMS OF Q_3 YIELDS:

$$X_{P3B}P_3 - X_{Q3B}Q_3 = B_6 \quad \text{OR} \quad Q_3 = \frac{X_{P3B}P_3 - B_6}{X_{Q3B}} \qquad (11)$$

REWRITING EQ.(2):

$$P_1\sin\Theta_1 - Q_1\cos\Theta_1 - \frac{X_{PAB}P_A}{X_{QAB}} = B_2 + \frac{B_3}{X_{QAB}} \qquad (12)$$

REWRITING EQ.(4):

$$P_1\cos\Theta_1 + Q_1\sin\Theta_1 - P_3\left[\cos(\Theta_1+\Theta_2) + \frac{X_{P3B}}{X_{Q3B}}\sin(\Theta_1+\Theta_2)\right]$$

$$= B_4 - B_6\frac{\sin(\Theta_1+\Theta_2)}{X_{Q3B}} \qquad (13)$$

REWRITING EQ (5)

$$-P_1\sin\Theta_1 + Q_1\cos\Theta_1 + P_3\left[\sin(\Theta_1+\Theta_2) - \frac{X_{P3B}\cos(\Theta_1+\Theta_2)}{X_{Q3B}}\right] = B_5 - \frac{B_6\cos(\Theta_1+\Theta_2)}{X_{Q3B}} \qquad (14)$$

THE ABOVE SYSTEM OF 4 EQUATIONS (EQS. (1), (12), (13), (14)) WITH 4 UNKNOWNS CAN BE EXPRESSED IN MATRIX FORM AS:

$$[A]\begin{Bmatrix} P_1 \\ Q_1 \\ P_A \\ P_3 \end{Bmatrix} = \{B\}$$

WHERE:

$$[A] = \begin{bmatrix} -\cos\Theta_1 & -\sin\Theta_1 & 1 & 0 \\ \sin\Theta_1 & -\cos\Theta_1 & -\frac{X_{PAB}}{X_{QAB}} & 0 \\ \cos\Theta_1 & \sin\Theta_1 & 0 & -\cos(\Theta_1+\Theta_2) - \frac{X_{P3B}}{X_{Q3B}}\sin(\Theta_1+\Theta_2) \\ -\sin\Theta_1 & \cos\Theta_1 & 0 & \sin(\Theta_1+\Theta_2) - \frac{X_{P3B}}{X_{Q3B}}\cos(\Theta_1+\Theta_2) \end{bmatrix}$$

$$\{B\} = \begin{Bmatrix} -W_1\sin\alpha + D_1\cos(\beta_{D1}+\alpha) - U_1\cos(\beta_{U1}+\alpha) \\ W_1\cos\alpha + D_1\sin(\beta_{D1}+\alpha) - U_1\sin(\beta_{U1}+\alpha) - \frac{W_1 X_{W1B}}{X_{QAB}} - \frac{D_1 X_{D1B}}{X_{QAB}} + \frac{U_1 X_{U1B}}{X_{QAB}} \\ -W_2\sin\alpha + D_2\cos(\beta_{D2}+\alpha) - U_2\cos(\beta_{U2}+\alpha) - (W_2 X_{W2B} + D_2 X_{D2B} - U_2 X_{U2B})\frac{\sin(\Theta_1+\Theta_2)}{X_{Q3B}} \\ W_2\cos\alpha + D_2\sin(\beta_{D2}+\alpha) - U_2\sin(\beta_{U2}+\alpha) - (W_2 X_{W2B} + D_2 X_{D2B} - U_2 X_{U2B})\frac{\cos(\Theta_1+\Theta_2)}{X_{Q3B}} \end{Bmatrix}$$

SEE FIGURE B-1

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FIGURE B-2 CONT'D

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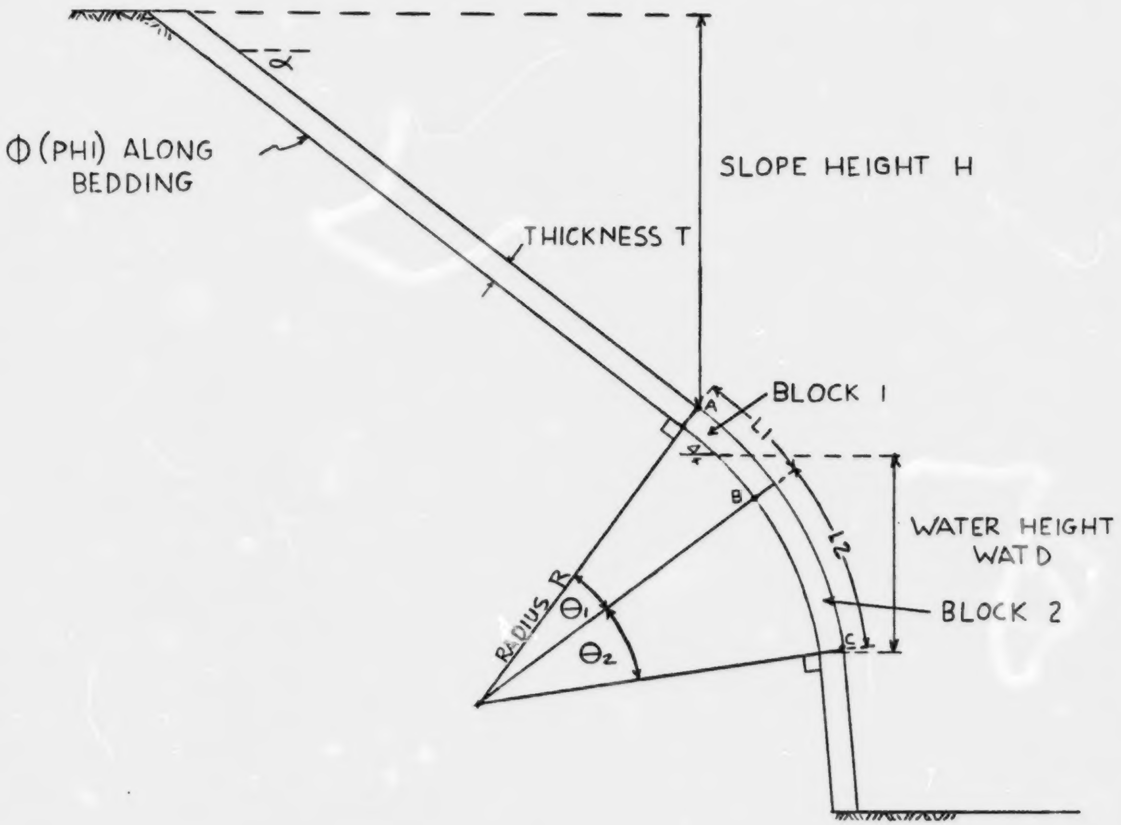

Φ (PHI) ALONG BEDDING
α
SLOPE HEIGHT H
THICKNESS T
A
BLOCK 1
L1
B
L2
WATER HEIGHT WAT D
BLOCK 2
C
RADIUS R
Θ_1
Θ_2

b) Mode 1 - Circular roll, both blocks on roll. (This may not be the critical case).

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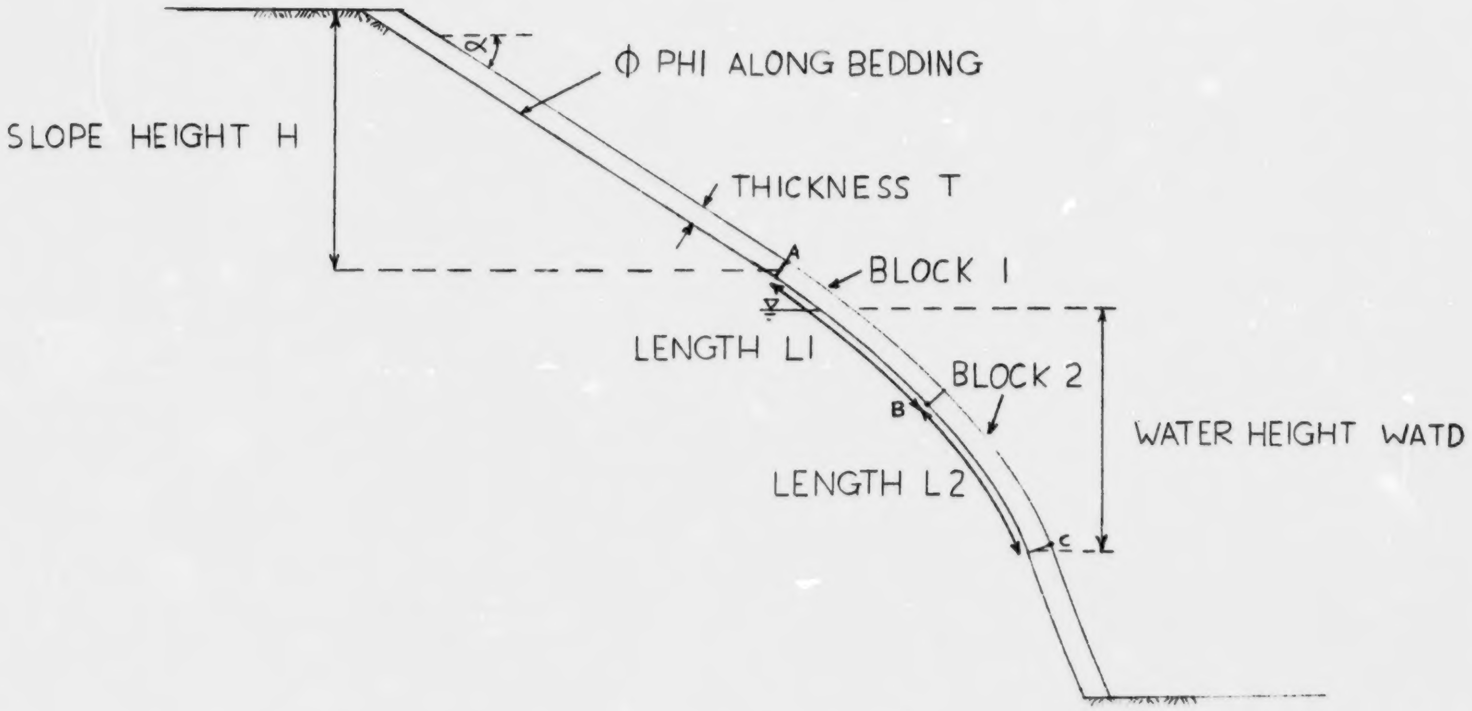
FIGURE B-3a
CONFIGURATION OF SLOPE
ANALYSED BY PROGRAM CURVBUK
IN MODE 1



α
ɸ PHI ALONG BEDDING
SLOPE HEIGHT H
THICKNESS T
A
BLOCK I
LENGTH LI
BLOCK 2
B
WATER HEIGHT WATD
LENGTH L2
C

a) Mode 2 - Completely general

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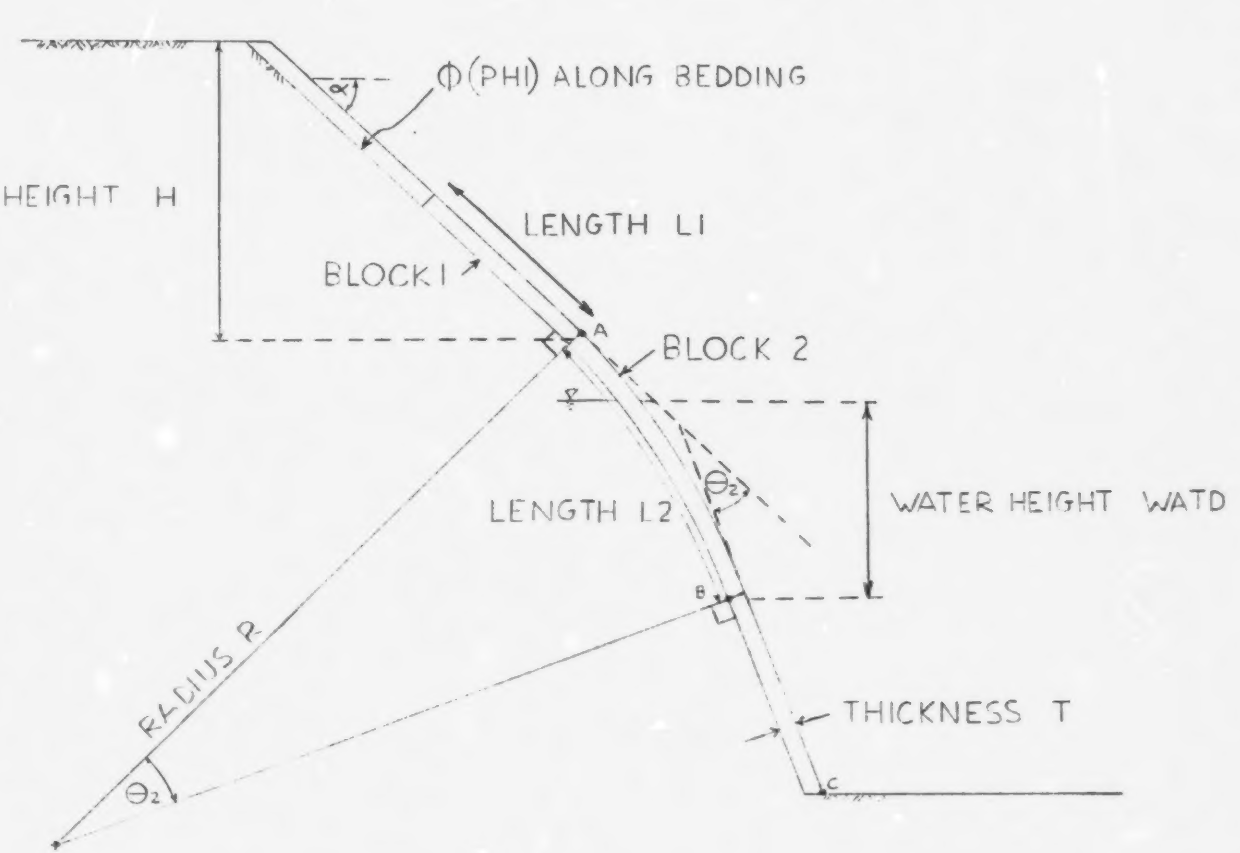
FIGURE B-3b
CONFIGURATION OF SLOPE
ANALYSED BY PROGRAM CURVBUK
IN MODE 2


Φ(PHI) ALONG BEDDING
α
SLOPE HEIGHT H
LENGTH L1
BLOCK 1
A
BLOCK 2
LENGTH L2
θ2
WATER HEIGHT WATD
B
RADIUS R
θ2
THICKNESS T
C

c) Mode 3 - Plane slab (block 1) above circular roll. Accessible only from Method 2 input using full screen editing.

FIGURE B-3c
CONFIGURATION OF SLOPE
ANALYSED BY PROGRAM CURVBUK
IN MODE 3

```
PROGRAM CURVBUK;
{REVISED TO 10/22/86 DSC}
{PROGRAM TO EVALUATE THE STABILITY OF A THREE HINGED
CURVED BEAM ON A ROCK SLOPE WITH WATER AND EXTERNAL FORCES
PROGRAM WRITTEN BY D.S. CAVERS 1985-86 BASED
ON PREVIOUS WORK BY DSC IN 1977-84
PROGRAM IS COPYRIGHT (C) 1985,1986 BY DS CAVERS AND HARDY ASSOC
THE SOLUTION MATRIX HAS BEEN PARTITIONED FROM THAT
SHOWN IN THE PAPER}

VAR

   D1DIST,D2DIST,THETA1,THETA2,P1,Q1,PA,B1,XPAB,XQAB,B2,B3:REAL;
   P3,Q3,QA,XP3B,XQ3B,B4,B5,B6,T,RADIUS:REAL;
   THETA1R,THETA2R,ALPHA,ALPHAR,BETAD1,BETAU1,XW1B,XD1B,XU1B:REAL;
   W1,W2,D1,D2,BETAD2,BETAU2,XW2B,XD2B,XU2B,TRADIUS:REAL;
   GAMMAW,GAMMAR,WATD,PHI,PHIR,C:REAL;
   FS,L1,L2,U1,U2,BETAU1R,BETAU2R,BETAD1R,BETAD2R:REAL;

   ANSWER:CHAR;
   CASEFLAG:BOOLEAN;
   TITLE:STRING[50];
   FILENAME:STRING[14];

   N,I,J,MODE,ROWVAR,NN,COLVAR,ANSWARN,DRYFLAG,XX,YY,XXOLD,YYOLD:INTEGER;
   COLVAROLD,VARFLAG,INPUTFLAG,ROWVAROLD:INTEGER;
   CH:CHAR;

   OUTPUT,B: ARRAY [1..4] OF REAL;

   FILEV:TEXT;
TYPE
   MATRIX = ARRAY[1..4,1..4] OF REAL;
VAR
   AA,A,ANS:MATRIX;

LABEL ECHO;
{*******************************************************************}
FUNCTION RAD_DEG(X:REAL):REAL;
BEGIN
RAD_DEG:=X*180.0/PI;
END;
{***************************************************************}
FUNCTION DEG_RAD(X:REAL):REAL;
BEGIN
DEG_RAD:=X*PI/180.0;
END;
{********************************************************************}
FUNCTION TAN(ANG:REAL):REAL;
LABEL ENDD;
BEGIN
IF ((ABS(ANG) =PI/2.0) OR (ABS(ANG)=3.0/2.0*PI)) THEN
   BEGIN
   TAN:=0.0;
   GOTO ENDD;
   END;
TAN := SIN(ANG)/COS(ANG);
ENDD:
END;
```

```
{*******************************************************************}
FUNCTION ARCSIN(X:REAL):REAL;
{COMPUTES ARCSIN AFTER ALGORITHM IN DEC MANUAL}

BEGIN
IF X=0.0 THEN ARCSIN:=0.0;
IF X=1.0 THEN ARCSIN:=PI/2.0;
IF X=-1.0 THEN ARCSIN:=-PI/2.0;
IF ((ABS(X)>0.0) AND (ABS(X)<1.0)) THEN
   BEGIN
   ARCSIN:=ARCTAN(X/SQRT(1.0-X*X));
   END;
IF ABS(X)>1.0 THEN
   BEGIN
   WRITELN('**** ERROR ARGUMENT TO ARCSIN IS >1.0');
   WRITELN('****        ARGUMENT IS  ',X);
   WRITELN('****        EXECUTION HALTED');
   WRITELN(LST,'**** ERROR ARGUMENT TO ARCSIN IS >1.0');
   WRITELN(LST,'****        ARGUMENT IS  ',X);
   WRITELN(LST,'****        EXECUTION HALTED');
   HALT;
   END;
END;{FUNCTION}
{**************************************************************}
PROCEDURE ZEROV;
BEGIN
TITLE:=('                                                  ');
MODE:=0;
THETA1R:=0.0;THETA2R:=0.0;
ALPHAR:=0.0;T:=0.0;L1:=0.0;L2:=0.0;
GAMMAW:=0.0;GAMMAR:=0.0;
WATD:=0.0;PHIR:=0.0;C:=0.0;
XPAB:=0.0;XQAB:=0.0;XP3B:=0.0;XQ3B:=0.0;
W1:=0.0;W2:=0.0;U1:=0.0;U2:=0.0;D1:=0.0;D2:=0.0;
XW1B:=0.0;XW2B:=0.0;RADIUS:=0.0;
XU1B:=0.0;XU2B:=0.0;
XD1B:=0.0;XD2B:=0.0;
BETAU1R:=0.0;BETAU2R:=0.0;BETAD2R:=0.0;BETAD1R:=0.0;
END;
{*****************************************************}
{$I GETDATE }
> {*************************************************************}
> PROCEDURE GetDate;
> type
>   DateStr = string[10];
>
> function Date: DateStr;
> type
>   regpack = record
>               ax,bx,cx,dx,bp,si,di,ds,es,flags: integer;
>             end;
>
> var
>   recpack:       regpack;                {record for MsDos call}
>   month,day:     string[2];
>   year:          string[4];
>   dx,cx:         integer;
>
> begin
>   with recpack do
>   begin
>     ax := $2a shl 8;
>   end;
>   MsDos(recpack);                         { call function }
>   with recpack do
>   begin
>     str(cx,year);                         {convert to string}
>     str(dx mod 256,day);                      { " }
>     str(dx shr 8,month);                      { " }
>   end;
>   date := month+'/'+day+'/'+year;
> end;
>
> begin
>   write(LST,date);
> end;
> {*************************************************************************}
{$I TIMEI }
> PROCEDURE TimeI;
> type
>   TimeString = string[8];
>
> function time: TimeString;
> type
>   regpack = record
>               ax,bx,cx,dx,bp,si,di,ds,es,flags: integer;
>             end;
>
> var
>   recpack:          regpack;                {assign record}
>   ah,al,ch,cl,dh:   byte;
>   hour,min,sec:     string[2];
>
> begin
>   ah := $2c;                                {initialize correct registers}
>   with recpack do
>   begin
>     ax := ah shl 8 + al;
>   end;
>   intr($21,recpack);                        {call interrupt}
>   with recpack do
>   begin
>     str(cx shr 8,hour);                     {convert to string}
>     str(cx mod 256,min);                        { " }
>     str(dx shr 8,sec);                          { " }
>   end;
>   time := hour+':'+min+':'+sec;
> end;
>
> begin
>   WRITELN(LST,'      ');
>   writeln(LST,time);
> end;
> {*******************************************************************}

{**********************************************************}
PROCEDURE XYWRITE(XXX,YYY:INTEGER);
LABEL ENDD;
BEGIN
```

```
     GOTOXY(1,24);WRITE('                                                ');
    GOTOXY(3,24);WRITE(XXX:5,YYY:5);
textcolor(15);TEXTBACKGROUND(0);
IF (YYY=3) THEN
BEGIN
  GOTOXY(11,3);
  WRITE(TITLE);
  GOTOXY(11,3);
  EXIT;
END;
IF((YYY>=5) AND (YYY<=11)) THEN
BEGIN
  IF (XXX=13) THEN
  BEGIN
    GOTOXY(XXX,YYY);
    CASE YYY OF
    5: WRITE(MODE:1);
    6: WRITE(#7,'ERROR');
    7: WRITE('              ');
    8: WRITE(RAD_DEG(ALPHAR):10:3);
    9: WRITE(RADIUS:10:3);
    10:WRITE(RAD_DEG(THETA1R):10:3);
    11:WRITE(RAD_DEG(THETA2R):10:3);
    END;
    EXIT;
  END;
  IF((XXX>=36) AND (XXX<=46)) THEN
  BEGIN
    GOTOXY(36,YYY);
    CASE YYY OF
    8:  WRITE(T:10:3);
    9:  WRITE(L1:10:3);
    10: WRITE(L2:10:3);
    END;
    EXIT;
  END;
END;

IF ((YYY>=14) AND (YYY<=23)) THEN
BEGIN
  IF((XXX=13)) THEN
  BEGIN
    GOTOXY(13,YYY);
    CASE YYY OF
    14:  WRITE(GAMMAW:10:3);
    15:  WRITE(GAMMAR:10:3);
    16:  WRITE(WATD:10:3);
    17:  WRITE(RAD_DEG(PHIR):10:3);
    18:  WRITE(C:10:3);
    19:  WRITE(#7);
    20:  WRITE(XPAB:10:3);
    21:  WRITE(XQAB:10:3);
    22:  WRITE(XP3B:10:3);
    23:  WRITE(XQ3B:10:3);
    END;
  EXIT;
  END;
  IF (XXX=30) THEN
  BEGIN
    GOTOXY(XXX,YYY);
    CASE YYY OF
    14:WRITE(W1:10);
    15:WRITE(W2:10);
    16:WRITE(U1:10);
    17:WRITE(U2:10);
    19:WRITE(D1:10);
    20:WRITE(D2:10);
    END;
  EXIT;
  END;
  IF((XXX>=47) AND (XXX<=57)) THEN
  BEGIN
    GOTOXY(47,YYY);
    CASE YYY OF
    14: WRITE(XW1B:10:3);
    15: WRITE(XW2B:10:3);
    16: WRITE(XU1B:10:3);
    17: WRITE(XU2B:10:3);
    19: WRITE(XD1B:10:3);
    20: WRITE(XD2B:10:3);
    END;
  EXIT;
  END;
  IF ((XXX>=67) AND (XXX<=77)) THEN
  BEGIN
    GOTOXY(67,YYY);
    CASE YYY OF
    16:  WRITE(RAD_DEG(BETAU1R):10:3);
    17:  WRITE(RAD_DEG(BETAU2R):10:3);
    19:  WRITE(RAD_DEG(BETAD1R):10:3);
    20:  WRITE(RAD_DEG(BETAD2R):10:3);
    END;
  END;
END;
ENDD:
END;{OF PROC}

{************************************************************************}
PROCEDURE HORIZARROW;
{FOR RIGHT-LEFT MOVES - MOVES CURSOR, WRITES OLD VALUE AND WRITES BOX}
  LABEL WRITTE;


BEGIN

XXOLD:=XX;YYOLD:=YY;
ROWVAROLD:=ROWVAR;
COLVAROLD:=COLVAR;
IF COLVAR=0 THEN
BEGIN
  COLVAR:=1;
  XX:=XXOLD;
  WRITE(#7);
  GOTO WRITTE;
END;
 {FOR COLVAR=1}
IF COLVAR=1 THEN
BEGIN
  IF ((((MODE=1) OR (MODE=3)) AND ((YY=19) OR (YY=20))) OR (YY=19)) THEN
  BEGIN
```

```
      WRITE(#7);
      COLVAR:=2;XX:=30;
      GOTO WRITTE;
    END;
    IF (YY=3) THEN
    BEGIN
      XX:=11;
      GOTO WRITTE;
    END;
    IF (((YY=9)) AND (MODE=2) AND (CH=#75)) THEN
    BEGIN
      XX:=36;
      ROWVAR:=YY;
      COLVAR:=2;
      WRITE(#7);
      GOTO WRITTE;
    END;
    IF (((YY=10) OR (YY=9)) AND (MODE=1) AND (CH=#77)) THEN
    BEGIN
      XX:=13;
      ROWVAR:=YY;
      COLVAR:=1;
      WRITE(#7);
      GOTO WRITTE;
    END;
    IF ((YY=10) AND (MODE=3) AND (CH=#77)) THEN
    BEGIN
      XX:=13;
      ROWVAR:=YY;
      COLVAR:=1;
      WRITE(#7);
      GOTO WRITTE;
    END;

    XX:=13;
    GOTO WRITTE;
  END;

  IF ((COLVAR=2) AND ((YY>=8) AND (YY<=10))) THEN
  BEGIN
    IF ((MODE=1) AND ((YY=9) OR (YY=10))) THEN
    BEGIN
      COLVAR:=1;XX:=13;WRITE(#7);GOTO WRITTE;
    END;
    IF ((MODE=3) AND (YY=10)) THEN
    BEGIN
      COLVAR:=1;XX:=13;WRITE(#7);GOTO WRITTE;
    END ELSE
    BEGIN
      XX:=36;
      GOTO WRITTE;
    END;
  END;

  IF ((YY=11) AND (COLVAR>=2)) THEN
  BEGIN
    XX:=13;COLVAR:=1;
    WRITE(#7);
    GOTO WRITTE;
  END;
```

```
IF ((COLVAR=3) AND ((YY>=8) AND (YY<=10))) THEN
BEGIN
  COLVAR:=2; XX:=36;
  WRITE(#7);
  GOTO WRITTE;
END;

IF ((COLVAR=2) AND ((YY>=14) AND (YY<=20)) AND (CH=(#77))) THEN
BEGIN
  IF ((MODE=1) OR (MODE=3) AND (YY<=17))  THEN
  BEGIN
    WRITE(#7);
    COLVAR:=1; XX:=13;
    GOTO WRITTE;
  END;
  IF ((MODE=2) AND ((YY=14) OR (YY=15))) THEN
  BEGIN
    COLVAR:=3;XX:=47;
    GOTO WRITTE;
  END;
  IF ((YY=18)) THEN
  BEGIN
    COLVAR:=1;XX:=13;YY:=YYOLD;
    WRITE(#7);
    GOTO WRITTE;
  END;
  XX:=30;
  GOTO WRITTE;
END;

IF ((COLVAR=2) AND (YY>=14) AND (YY<=20)) THEN
BEGIN
  IF ((CH=(#75)) AND ((YY=14) OR (YY=15))) THEN
    BEGIN
      COLVAR:=1;XX:=13;
      GOTO WRITTE;
    END;
  XX:=30;
  GOTO WRITTE;
END;
IF ((COLVAR=2) AND (CH=#77) AND (ROWVAR>=21)) THEN
BEGIN
  COLVAR:=1;XX:=13;
  WRITE(CHAR(#7));
  GOTO WRITTE;
END;
IF ((COLVAR=3) AND ((YY>=14) AND (YY<=20))) THEN
BEGIN
  XX:=47;
  GOTO WRITTE;
END;

IF ((COLVAR=4) AND ((YY>=16) AND (YY<=20))) THEN
BEGIN
  XX:=67;
  GOTO WRITTE;
END;

IF (COLVAR>=5) THEN
```

```
BEGIN
  COLVAR:=4;XX:=67;
  WRITE(CHAR(#7));
  GOTO WRITTE;
END;
XX:=XXOLD;YY:=YYOLD;COLVAR:=COLVAROLD;
WRITE ('ERROR');
WRITE(#7);

WRITTE:

TEXTBACKGROUND(0);
TEXTCOLOR(15);
XYWRITE(XXOLD,YYOLD);
GOTOXY(XX,YY);
TEXTBACKGROUND(7);TEXTCOLOR(0);
WRITE('            ');
IF (YY<>3) THEN EXIT;
XX:=11;
TEXTBACKGROUND(7);TEXTCOLOR(0);
GOTOXY(XX,YY);
WRITE(TITLE);
TEXTBACKGROUND(0);TEXTCOLOR(15);
END;
{*******************************************************************}
PROCEDURE RARR;
{RIGHT ARROW}

BEGIN
COLVAROLD:=COLVAR;
COLVAR:=COLVAR+1;
HORIZARROW;
CASEFLAG:=TRUE;
END;
{*******************************************************************}
PROCEDURE LARR;{LEFT ARROW}
BEGIN
COLVAROLD:=COLVAR;
COLVAR:=COLVAR-1;
HORIZARROW;
CASEFLAG:=TRUE;
END;
{*******************************************************************}

PROCEDURE VERTARROW;
{FOR UP AND DOWN ARROW MOVES
   -MOVES CURSOR
   -CHECKS ILLEGAL AREAS
   -WRITES OLD VALUE
   -WRITES BOX}

VAR
  WRITEFLAG:BOOLEAN;
  LABEL  WRITTE;

BEGIN
WRITEFLAG:=TRUE;
XXOLD:=XX;
YYOLD:=YY;
```

```
IF (ROWVAR<3) THEN
BEGIN
  ROWVAR:=3;
  YY:=ROWVAR;
  WRITE(#7);
  GOTO WRITTE;
END;

IF ((ROWVAR=4) AND (CH=(#72))) THEN
BEGIN
  ROWVAR:=3;
  COLVAR:=1;
  XX:=11;
  YY:=3;
  GOTO WRITTE;
END;

IF ((ROWVAR=4) AND (CH=(#80))) THEN
BEGIN
  ROWVAR:=8;
  YY:=8;{TO SKIP MODE}
  COLVAR:=1;
  XX:=13;
  GOTO WRITTE;
END;

IF((ROWVAR=7) AND (CH=(#72))) THEN
BEGIN
  ROWVAR:=3;YY:=3;
  COLVAR:=1;XX:=11;
  GOTO WRITTE;
END;

IF ((ROWVAR>=9) AND (ROWVAR<=11) AND ((MODE=1) OR  (MODE=3)) AND (COLVAR=1) AND
BEGIN
  YY:=ROWVAR;
  GOTO WRITTE;
END;
IF ((ROWVAR=9) AND (COLVAR=1) AND (MODE=2) AND (CH=#80)) THEN
BEGIN
  YY:=10;ROWVAR:=10;
  GOTO WRITTE;
END;

IF ((ROWVAR=11) AND (COLVAR=2) AND (MODE=2) AND (CH=#80)) THEN
BEGIN
  YY:=14;ROWVAR:=14;
  XX:=47;COLVAR:=3;
  GOTO WRITTE;
END;

IF ((ROWVAR>=12) AND (ROWVAR<=14) AND (COLVAR=1) AND (CH=#80)) THEN
BEGIN
  ROWVAR:=14;YY:=14;
  XX:=13;
END;

IF ((ROWVAR=9)AND(COLVAR=2)AND(CH=#80)AND(MODE=1)) THEN
BEGIN
  YY:=19;ROWVAR:=19;
  COLVAR:=2;XX:=30;
  GOTO WRITTE;
END;

IF ((ROWVAR=10)AND(COLVAR=2)AND(CH=#80)AND(MODE=3)) THEN
BEGIN
  YY.=19;ROWVAR:=19;
  COLVAR:=2;XX:=30;
  GOTO WRITTE;
END;

IF ((ROWVAR=18)AND(COLVAR=2)AND(MODE=1)AND(CH=#72)) THEN
BEGIN
  YY:=8;ROWVAR:=8;
  COLVAR:=2;XX:=36;
  GOTO WRITTE;
END;

IF ((ROWVAR=18)AND(COLVAR=2)AND(MODE=3)AND(CH=#72)) THEN
BEGIN
  YY:=9;ROWVAR:=9;
  COLVAR:=2;XX:=36;
  GOTO WRITTE;
END;

IF ((ROWVAR=15) AND (CH=#72) AND (COLVAR=2)) THEN
BEGIN
  ROWVAR:=10;YY:=10;
  COLVAR:=2;XX:=36;
  GOTO WRITTE;
END;

IF ((ROWVAR=8) OR (ROWVAR=9)) THEN
BEGIN
  YY:=ROWVAR;
  IF ((ROWVAR=9) AND (MODE=2) AND (COLVAR=1) AND (CH=#80)) THEN
  BEGIN
    ROWVAR:=10;YY:=10;
    GOTO WRITTE;
  END;
  IF ((ROWVAR=9) AND (MODE=2) AND (COLVAR=1) AND (CH=#72)) THEN
  BEGIN
    ROWVAR:=8;YY:=8;
    GOTO WRITTE;
  END;
  IF COLVAR=1 THEN
  BEGIN
    YY:=ROWVAR;
    XX:=13;
    GOTO WRITTE;
  END;
  IF COLVAR=2 THEN
  BEGIN
   YY:=ROWVAR;
   XX:=36;
   GOTO WRITTE;
  END;
END;

IF(((ROWVAR>=10) AND (ROWVAR<=14)) AND (CH=(#80))) THEN
```

```
BEGIN
  IF ((COLVAR=1) AND (MODE=2)AND((ROWVAR=10) OR (ROWVAR=11))) THEN
  BEGIN
    YY:=ROWVAR;
    GOTO WRITTE;
  END;
  IF ((COLVAR=2) AND (ROWVAR=10) AND (CH=#80)) THEN
  BEGIN
    ROWVAR:=10;YY:=10;
    XX:=36;
    GOTO WRITTE;
  END;
  IF ((COLVAR=2) AND (ROWVAR=11) AND (CH=#80)) THEN
  BEGIN
    ROWVAR:=16;YY:=16;
    XX:=30;
    GOTO WRITTE;
  END;
  IF ((COLVAR=1) AND (YY=12)) THEN
  BEGIN
    ROWVAR:=14;YY:=14;
    XX:=13;
    GOTO WRITTE;
  END;
  IF (COLVAR=1) THEN
  BEGIN
    YY:=ROWVAR;
    XX:=13;
    GOTO WRITTE;
  END;
  IF COLVAR=2 THEN
  BEGIN
    XX:=36;
    GOTO WRITTE;
  END;
END;

IF(((ROWVAR>=10) AND (ROWVAR<=14)) AND (CH=(#72))) THEN
BEGIN
  IF ((COLVAR=1) AND (MODE=2)AND(ROWVAR=13)) THEN
  BEGIN
    ROWVAR:=11;YY:=11;
    XX:=13;
    GOTO WRITTE;
  END;
  IF ((COLVAR=2)) THEN
  BEGIN
    ROWVAR:=10;YY:=10;
    XX:=36;
    GOTO WRITTE;
  END;
  IF ((COLVAR=1) AND (ROWVAR=13)) THEN
  BEGIN
    ROWVAR:=11;YY:=11;
    XX:=13;
    GOTO WRITTE;
  END;
  IF ((COLVAR=3) AND (ROWVAR=13)) THEN
  BEGIN
    ROWVAR:=10;YY:=10;
```

```
      XX:=36;
      COLVAR:=2;
      GOTO WRITTE;
    END;
  END;

  IF ((ROWVAR=18) AND (XX>=30) AND (CH=(#72))) THEN
  BEGIN
    IF(MODE=1) THEN
    BEGIN
      ROWVAR:=8;YY:=8;
      XX:=36;
      COLVAR:=2;
      GOTO WRITTE;
    END;
    IF(MODE=3) THEN
    BEGIN
      ROWVAR:=9;YY:=9;
      XX:=36;
      COLVAR:=2;
      GOTO WRITTE;
    END;
    ROWVAR:=17;YY:=17;
    GOTO WRITTE;
  END;

  IF ((ROWVAR=19) AND (XX=13) AND (CH=(#72))) THEN
  BEGIN
    ROWVAR:=18;YY:=18;
    GOTO WRITTE;
  END;

  IF ((ROWVAR=18) AND (XX>=30) AND (CH=(#80))) THEN
  BEGIN
    ROWVAR:=19;YY:=19;
    GOTO WRITTE;
  END;

  IF ((ROWVAR=19) AND (XX=13)  AND (CH=(#80))) THEN
  BEGIN
    IF ((MODE=1) OR (MODE=3)) THEN
    BEGIN
      WRITE(#7);
      ROWVAR:=ROWVAROLD; YY:=YYOLD;
      GOTO WRITTE;
    END;
    ROWVAR:=20;YY:=20;
    GOTO WRITTE;
  END;

  IF (((ROWVAR=21) AND (XX>=30)) OR ((ROWVAR=24) AND (XX<=25))) THEN
  BEGIN
    ROWVAR:=ROWVAROLD; YY:=YYOLD;
    WRITE(#7);
    GOTO WRITTE;
  END;

  IF ((ROWVAR<=15) AND (COLVAR=4)) THEN
  BEGIN
    ROWVAR:=ROWVAROLD; YY:=YYOLD;
  WRITE(#7);
  GOTO WRITTE;
END;

YY:=ROWVAR;

WRITTE:
TEXTBACKGROUND(0);TEXTCOLOR(15);
XYWRITE(XXOLD,YYOLD);
GOTOXY(XX,YY);
TEXTBACKGROUND(7);TEXTCOLOR(0);
WRITE('          ');
TEXTBACKGROUND(0);TEXTCOLOR(15);
IF (YY<>3) THEN EXIT;
XX:=11;
TEXTBACKGROUND(7);TEXTCOLOR(0);
GOTOXY(XX,YY);
WRITE(TITLE);
TEXTBACKGROUND(0);TEXTCOLOR(15);
END;
{***********************************************************************}
PROCEDURE DARR;{DOWN ARROW}
BEGIN
COLVAROLD:=COLVAR;
ROWVAROLD:=ROWVAR;
ROWVAR:=ROWVAR+1;
VERTARROW;
CASEFLAG:=TRUE;
END;
{***********************************************************************}
PROCEDURE UARR;{UP ARROW}
BEGIN
COLVAROLD:=COLVAR;
ROWVAROLD:=ROWVAR;
ROWVAR:=ROWVAR-1;
VERTARROW;
CASEFLAG:=TRUE;
END;
{*************************************************************************}
PROCEDURE SCREENGEN;
{WRITES OUT SCREEN AS REQ'D FROM MAIN PROGRAM
 THIS PROC REFRESHES SCREEN AND DOES CALCS}

BEGIN
CLRSCR;
TEXTCOLOR(15);
GOTOXY(4,1);WRITE('CURVBUK - 3 HINGED CURVED STRATA BUCKLING - INPUT');
GOTOXY(3,3);WRITE('TITLE');
GOTOXY(11,3);WRITE(TITLE);
GOTOXY(3,5);WRITE('MODE');
GOTOXY(13,5);WRITE(MODE:1);
GOTOXY(33,6);WRITE('GEOMETRIC DATA');
GOTOXY(3,8);WRITE('ALPHA');

IF MODE=2 THEN
BEGIN
  GOTOXY(3,9);WRITE('N/A-MODE 2');
END
ELSE
BEGIN
```

```
    GOTOXY(3,9);WRITE('RADIUS');
  END;
  GOTOXY(3,10);WRITE('THETA1');
  GOTOXY(3,11);WRITE('THETA2');
  GOTOXY(13,8);WRITE(RAD_DEG(ALPHAR):10:3);

  IF((MODE=1) OR (MODE=3)) THEN
  BEGIN
    GOTOXY(13,9);WRITE(RADIUS:10:3);
  END;
  GOTOXY(13,10);WRITE(RAD_DEG(THETA1R):10:3);
  GOTOXY(13,11);WRITE(RAD_DEG(THETA2R):10:3);
  GOTOXY(25,8);WRITE('T');
  GOTOXY(25,9);WRITE('L1');

  IF MODE=1 THEN
  BEGIN
    GOTOXY(50,9);WRITE('CALCULATED IN MODE 1');
    GOTOXY(50,10); WRITE('CALCULATED IN MODE 1');
  END;

  IF MODE=3 THEN
  BEGIN
    GOTOXY(50,10); WRITE('CALCULATED IN MODE 3');
  END;

  GOTOXY(25,10);WRITE('L2');
  GOTOXY(36,8);WRITE(T:10:3);
  GOTOXY(36,9);WRITE(L1:10:3);
  GOTOXY(36,10);WRITE(L2:10:3);
  GOTOXY(35,12);WRITE('FORCE DATA');

  IF (MODE=1) THEN
  BEGIN
    GOTOXY(35,13);WRITE('CALCULATED(MODE=1)');
    GOTOXY(3,19);WRITE('CALCULATED');
  END;

  IF (MODE=3) THEN
  BEGIN
    GOTOXY(35,13);WRITE('CALCULATED(MODE=3)');
    GOTOXY(3,19);WRITE('CALCULATED');
  END;

  GOTOXY(3,14);WRITE('GAMMAW');
  GOTOXY(3,15);WRITE('GAMMAR');
  GOTOXY(3,16);WRITE('WATD');
  GOTOXY(3,17);WRITE('PHI');
  GOTOXY(3,18);WRITE('C');
  GOTOXY(3,20);WRITE('XPAB');
  GOTOXY(3,21);WRITE('XQAB');
  GOTOXY(3,22);WRITE('XP3B');
  GOTOXY(3,23);WRITE('XQ3B');
  GOTOXY(13,14);WRITE(GAMMAW:10:3);
  GOTOXY(13,15);WRITE(GAMMAR:10:3);
  GOTOXY(13,16);WRITE(WATD:10:3);
  GOTOXY(13,17);WRITE(RAD_DEG(PHIR):10:3);
  GOTOXY(13,18);WRITE(C:10:3);
  GOTOXY(13,20);WRITE(XPAB:10:3);
  GOTOXY(13,21);WRITE(XQAB:10:3);
```

```
GOTOXY(13,22);WRITE(XP3B:10:3);
GOTOXY(13,23);WRITE(XQ3B:10:3);
GOTOXY(26,14);WRITE('W1');
GOTOXY(26,15);WRITE('W2');
GOTOXY(26,16);WRITE('U1');
GOTOXY(26,17);WRITE('U2');
GOTOXY(26,19);WRITE('D1');
GOTOXY(26,20);WRITE('D2');
GOTOXY(30,14);WRITE(W1:10);
GOTOXY(30,15);WRITE(W2:10);
GOTOXY(30,16);WRITE(U1:10);
GOTOXY(30,17);WRITE(U2:10);
GOTOXY(30,19);WRITE(D1:10);
GOTOXY(30,20);WRITE(D2:10);
GOTOXY(30,18);WRITE('---------------------------');
GOTOXY(42,14);WRITE('XW1B');
GOTOXY(42,15);WRITE('XW2B');
GOTOXY(42,16);WRITE('XU1B');
GOTOXY(42,17);WRITE('XU2B');
GOTOXY(42,19);WRITE('XD1B');
GOTOXY(42,20);WRITE('XD2B');
GOTOXY(47,14);WRITE(XW1B:10:3);
GOTOXY(47,15);WRITE(XW2B:10:3);
GOTOXY(47,16);WRITE(XU1B:10:3);
GOTOXY(47,17);WRITE(XU2B:10:3);
GOTOXY(47,19);WRITE(XD1B:10:3);
GOTOXY(47,19);WRITE(XD1B:10:3);
GOTOXY(47,20);WRITE(XD2B:10:3);
GOTOXY(60,16);WRITE('BETAU1');
GOTOXY(60,17);WRITE('BETAU2');
GOTOXY(60,19);WRITE('BETAD1');
GOTOXY(60,20);WRITE('BETAD2');
GOTOXY(67,16);WRITE(RAD_DEG(BETAU1R):10:3);
GOTOXY(67,17);WRITE(RAD_DEG(BETAU2R):10:3);
GOTOXY(67,19);WRITE(RAD_DEG(BETAD1R):10:3);
GOTOXY(67,20);WRITE(RAD_DEG(BETAD2R):10:3);
GOTOXY(3,25);WRITE('[F1] PRNT,SAVE  [F2] CALC INPUT  [F4] OUTPUT [F5] CALC PRNT
END;
{*********************************************************************}
PROCEDURE VARL(XX,YY:INTEGER; VAR VARFLAG:INTEGER);
{RETURNS VARFLAG NUMBER FOR VARIABLES}
BEGIN
IF (XX=13) THEN
BEGIN
  CASE YY OF
  5:  VARFLAG:=1;
  8:  VARFLAG:=2;
  9:  VARFLAG:=3;
  10:  VARFLAG:=4;
  11:  VARFLAG:=5;
  14:  VARFLAG:=6;
  15:  VARFLAG:=7;
  16:  VARFLAG:=8;
  17:  VARFLAG:=9;
  18:  VARFLAG:=10;
  20:  VARFLAG:=11;
  21:  VARFLAG:=12;
  22:  VARFLAG:=13;
  23:  VARFLAG:=14;
  END;
```

```
END;

IF XX=36 THEN
BEGIN
  CASE YY OF
  8:  VARFLAG:=15;
  9:  VARFLAG:=16;
  10:  VARFLAG:=17;
  END;
END;

IF XX=30 THEN
BEGIN
  CASE YY OF
  14:  VARFLAG:=18;
  15:  VARFLAG:=19;
  16:  VARFLAG:=20;
  17:  VARFLAG:=21;
  19:  VARFLAG:=22;
  20:  VARFLAG:=23;
  END;
END;

IF XX=47 THEN
BEGIN
  CASE YY OF
  14:  VARFLAG:=24;
  15:  VARFLAG:=25;
  16:  VARFLAG:=26;
  17:  VARFLAG:=27;
  19:  VARFLAG:=28;
  20:  VARFLAG:=29;
  END;
END;

IF XX=67 THEN
  CASE YY OF
  16:  VARFLAG:=30;
  17:  VARFLAG:=31;
  19:  VARFLAG:=32;
  20:  VARFLAG:=33;
  END;
END;{PROC}
{*******************************************************}
PROCEDURE PORPRES;
{CALCULATES PORE PRESSURE FORCES, BETA ANGLES AND LEVER ARMS}

VAR

A,B,DELTAD,CHORD1,CHORD2,A2,B2,DELTAD2:REAL;
Y1,Y2,X,V1,V2,R,G,PSIR:REAL;
RECTAREA,TRIAREA:REAL;
LABEL
   ENDD,LESSZERO,LESSV2,GREAV2,GREAV1;
BEGIN
{CONVENTION WILL BE THAT WATER DIST WATD POSITIVE IS ABOVE
THE UPPER HINGE POINT AND THAT IT IS MEASUREED VERTICALLY}

{CALCULATE IF WATD IS ABOVE REFLECTED INNER HINGE POINT A}
R:=RADIUS;
```

```
IF (MODE=3) THEN
BEGIN
  V1:=L1*SIN(ALPHAR);
  V2:=R*(COS(ALPHAR+THETA1R)-COS(ALPHAR+THETA1R+THETA2R));
END;
IF MODE=1 THEN
BEGIN
  V1:=R*(COS(ALPHAR)-COS(ALPHAR+THETA1R));
  V2:=R*(COS(ALPHAR+THETA1R)-COS(ALPHAR+THETA1R+THETA2R));
END;
{CHECK WHERE WATD IS FOR DIFFERENT CASES}
IF (WATD<=0.0) THEN GOTO LESSZERO;
IF (WATD<=V2) THEN GOTO LESSV2;
IF ((WATD>V2) AND (WATD<=V2+V1)) THEN GOTO GREAV2;
IF (WATD>(V2+V1)) THEN GOTO GREAV1;

LESSZERO:
DRYFLAG:=1;
XU1B:=0.0;XU2B:=0.0;U1:=0.0;U2:=0.0;
GOTO ENDD;

LESSV2:
{FOR WATER ON LOWER BLOCK ONLY}
U1:=0.0;
XU1B:=0.0;
BETAU1R:=0.0;
{PSIR IS THE ANGLE DEFINING WATER FORCE LOCATION}
G:=R*COS(ALPHAR+THETA1R+THETA2R);
PSIR:=ARCSIN((G+WATD)/R)-PI/2.0+ALPHAR+THETA1R+THETA2R;
CHORD2:=R*PSIR;
U2:=GAMMAW*WATD*CHORD2/2.0;
XU2B:=R*SIN(THETA2R - PSIR/3.0);
BETAU2R:=PI/2.0-ALPHAR-THETA1R-THETA2R+PSIR/3.0; {DSC 7/23/86 CH 2 TO 3}
GOTO ENDD;

GREAV2:
{FOR WATER PART WAY UP THE UPPER BLOCK BLOCK 1}
{UPPER BLOCK}
G:=R*COS(ALPHAR+THETA1R+THETA2R);
IF (MODE=3) THEN
BEGIN
  CHORD1:=(WATD-V2)/SIN(ALPHAR);
  U1:=GAMMAW*(WATD-V2)*CHORD1/2.0;
  XU1B:=CHORD1/3.0;
  BETAU1R:=PI/2.0-ALPHAR;
END;
IF (MODE=1) THEN
BEGIN
PSIR:=ARCSIN((WATD+G)/R);
CHORD1:=R*(PSIR-PI/2.0+ALPHAR+THETA1R);
U1:=CHORD1*(WATD-V2)*GAMMAW/2.0;
BETAU1R:=PI/3.0+PSIR/3.0-2.0*ALPHAR/3.0-2.0*THETA1R/3.0;{CH DSC 7/23/86 TO MG}
Y1:=CHORD1/3.0;
XU1B:=R*SIN(Y1/R);
END;
{FOR LOWER BLOCK}
CHORD2:=R*THETA2R;
RECTAREA:=(WATD-V2)*CHORD2*GAMMAW;
TRIAREA:=V2*CHORD2*GAMMAW/2.0;
U2:=TRIAREA+RECTAREA;
```

```
X:=(RECTAREA*CHORD2/2.0 + TRIAREA*CHORD2/3.0)/U2;
Y2:=CHORD2-X;
BETAU2R:=PI/2.0 - ALPHAR - THETA1R - (Y2/R);
XU2B:=R*SIN(Y2/R);
GOTO ENDD;

GREAV1:
{FOR WATER ABOVE UPPER BLOCK}
{UPPER BLOCK}
IF (MODE=3) THEN
BEGIN
  RECTAREA:=(WATD-V1-V2)*GAMMAW*L1;
  TRIAREA:=GAMMAW*V1*L1/2.0;
  U1:=TRIAREA+RECTAREA;
  XU1B:=(RECTAREA*L1/2.0 + TRIAREA*L1/3.0)/U1;
  BETAU1R:=PI/2.0 - ALPHAR;
END;
IF (MODE =1) THEN
BEGIN
  CHORD1:=R*THETA1R;
  RECTAREA:=CHORD1*(WATD-V1-V2)*GAMMAW;
  TRIAREA:=V1*GAMMAW*CHORD1/2.0;
  U1:=TRIAREA+RECTAREA;
  Y1:=(RECTAREA*CHORD1/2.0 + TRIAREA*CHORD1/3.0)/U1;
  BETAU1R:=PI/2.0-ALPHAR-THETA1R+(Y1/R);
  XU1B:=R*SIN(Y1/R);
END;
{LOWER BLOCK}
 CHORD2:=R*THETA2R;
 RECTAREA:=(WATD-V2)*GAMMAW*CHORD2;
 TRIAREA:=V2*GAMMAW*CHORD2/2.0;
 U2:=RECTAREA+TRIAREA;
 X:=(RECTAREA*CHORD2/2.0 + TRIAREA*CHORD2/3.0)/U2;
 Y2:=CHORD2-X;
 BETAU2R:=PI/2.0-THETA1R-ALPHAR-(Y2/R);
 XU2B:=R*SIN(Y2/R);
 ENDD:
 END;{PROCEDURE END}



{************************************************************************}
PROCEDURE WEIGHTS;
BEGIN
W1:=L1*T*GAMMAR;
W2:=L2*T*GAMMAR;
END;
{************************************************************************}

PROCEDURE GEOM;
VAR
A,B,A2,B2,R:REAL;
{CALCULATES GEOMTRICAL LEVER ARMS FOR WEIGHTS ETC}

BEGIN
IF (MODE=1) THEN
BEGIN
  R:=RADIUS;
  A:=(RADIUS+T/2.0)*SIN(ALPHAR+THETA1R/2.0);
  B:=RADIUS*SIN(ALPHAR+THETA1R);
  XW1B:=B-A;
END;
IF ((MODE=1) OR (MODE=3)) THEN
BEGIN
  R:=RADIUS;
  A2:=(R+T/2.0)*SIN(ALPHAR+THETA1R+(THETA2R/2.0));
  B2:=R*SIN(ALPHAR+THETA1R);
  XW2B:=A2-B2;
END;
IF (MODE=3) THEN
BEGIN
  XW1B:=L1*COS(ALPHAR)/2.0 - T*SIN(ALPHAR)/2.0;
END;
END;
{*************************************************************************}

PROCEDURE READDISC;
{READS OLD DATA FROM DISC}
BEGIN
WRITELN('THIS ROUTINE IS NOT USED ROUTINELY - CHECK ALL DATA');
WRITELN('INPUT DISC AND FILENAME:    ');
              READLN(FILENAME);
              ASSIGN(FILEV,FILENAME);
              RESET(FILEV);
              READLN(FILEV,TITLE);
              READLN(FILEV,T);
              READLN(FILEV,ALPHA);
              ALPHAR:=DEG_RAD(ALPHA);
              READLN(FILEV,GAMMAR);
              READLN(FILEV,GAMMAW);
              READLN(FILEV,WATD);
              READLN(FILEV,D1);
              READLN(FILEV,D2);
              READLN(FILEV,BETAD1);
              READLN(FILEV,BETAD2);
              BETAD1R:=DEG_RAD(BETAD1);
              BETAD1R:=DEG_RAD(BETAD2);
              READLN(FILEV,XD1B);
              READLN(FILEV,XD2B);
              READLN(FILEV,PHI);
              PHIR:=DEG_RAD(PHI);
              READLN(FILEV,C);
              READLN(FILEV,MODE);
              IF MODE = 1
                 THEN BEGIN
                 READLN(FILEV,RADIUS);
                 READLN(FILEV,THETA1);
                 THETA1R:=DEG_RAD(THETA1);
                 READLN(FILEV,THETA2);
                 THETA2R:=DEG_RAD(THETA2);
                 END;
              IF((MODE=2) OR (MODE=3)) THEN
              BEGIN
                 READLN(FILEV,THETA1);
                 THETA1R:=DEG_RAD(THETA1);
                 READLN(FILEV,THETA2);
                 READLN(FILEV,THETA2);
                 READLN(FILEV,L1);
                 READLN(FILEV,L2);
                 READLN(FILEV,W1);
                 READLN(FILEV,W2);
                 READLN(FILEV,XW1B);
                 READLN(FILEV,XW2B);
                 READLN(FILEV,U1);
                 READLN(FILEV,U2);
                 READLN(FILEV,XU1B);
                 READLN(FILEV,XU2B);
                 READLN(FILEV,BETAU1);
                 BETAU1R:=DEG_RAD(BETAU1);
                 READLN(FILEV,BETAU2);
                 BETAU2R:=DEG_RAD(BETAU2);
                 READLN(FILEV,XPAB);
                 READLN(FILEV,XQAB);
                 READLN(FILEV,XP3B);
                 READLN(FILEV,XQ3B);
                 END;
CLOSE(FILEV);
END;
{***********************************************************************}
PROCEDURE INITIAL;
{DISPLAYS INITIAL SCREEN}
{DECIDES ON METHOD OF DATA INPUT AND SETS FLAG; DECIDES MODE}

BEGIN
DELETE(TITLE,1,50);
CLRSCR;GOTOXY(22,5);
TEXTBACKGROUND(15);TEXTCOLOR(0);
WRITE('               CURVBUK                  ');
GOTOXY(22,6);
WRITE('                                        ');
GOTOXY(22,7);            HARDY BBT LTD
WRITE('         (C) D.S. CAVERS,^1986          ');  GOTO (14,8);
GOTOXY(22,9);                                     WRITE ('CONTACT D.S.CAVERS
WRITE('                                        ');     (604)294-3811 FOR FURTHER
GOTOXY(22,10);                                         INFORMATION');
WRITE('       ANALYSIS OF CURVED STRATA        ');
GOTOXY(22,11);
WRITE('    BY THREE HINGED BUCKLING METHOD     ');
TEXTBACKGROUND(0);TEXTCOLOR(15);
GOTOXY(35,13);WRITE('DISCLAIMER');
TEXTCOLOR(7);GOTOXY(7,16);
WRITE('THE USER IS COMPLETELY RESPONSIBLE FOR DETERMINING THE SUITABILITY,');
GOTOXY(7,17);
WRITE('APPLICABILITY AND CORRECTNESS OF THIS PROGRAM AND ALL RESULTS FOR');
GOTOXY(7,18);
WRITE('THE USERS PROBLEM.  D.S.CAVERS AND HARDY ASSOCIATES ARE NOT');
GOTOXY(7,19);
WRITE('RESPONSIBLE FOR APPLICATION OF RESULTS OR IDEAS IN THIS PROGRAM');
GOTOXY(7,20);
WRITE('OR ARISING OUT OF THIS PROGRAM.');
TEXTBACKGROUND(15);TEXTCOLOR(0);
GOTOXY(29,21);while keypressed read(kbd,ch);
WRITE('HIT ANY KEY TO ACCEPT');
TEXTBACKGROUND(0);TEXTCOLOR(15);
REPEAT UNTIL KEYPRESSED; CLRSCR;
REPEAT
  WRITELN('CHOOSE MODE:  ');
  WRITELN;
  WRITELN('    MODE = 1:   MANY OF THE PARAMETERS ARE CALCULATED');
  WRITELN;
  WRITELN('    MODE = 2:   INPUT ALL OF THE PARAMETERS');
  WRITELN;
  WRITELN('    MODE = 3:   BLOCK 1 STRAIGHT, BLOCK 2 CURVED');
  WRITELN;
  GOTOXY(5,10);WRITE('CHOOSE 1,2 OR 3 <RET>   ');
  READLN(MODE);
UNTIL MODE IN [1,2,3];
REPEAT
GOTOXY(5,12);
  WRITELN;
  WRITELN('CHOOSE INPUT METHOD');
  WRITELN;
  WRITELN('     1 = ONCE THROUGH, NO EDITING');
  WRITELN;
  WRITELN('     2 = INPUT AND OUTPUT SCREENS, FULL EDITING');
  WRITELN('         MODE 3 CAN ONLY BE RUN IN METHOD 2     ');
  WRITELN;
  WRITE('  CHOOSE 1 OR 2 <RET>   ');
  READLN(INPUTFLAG);
UNTIL INPUTFLAG IN [1,2];
CLRSCR;
IF INPUTFLAG=2 THEN
BEGIN
 REPEAT
    GOTOXY(5,5);WRITE('DO YOU WISH TO READ DATA FROM DISC? Y OR N <RET>   ');
    READLN(ANSWER);
  UNTIL ANSWER IN ['Y','N'];
  IF ANSWER = 'Y' THEN READDISC;
  XX:=11;
  YY:=3;
  ROWVAR:=3;
  COLVAR:=1;
END;
END;{CALLS ARE GENERATED BY THE MAIN PROG}

{*********************************************************************}
PROCEDURE SLOPE_CHECK;
{CHECKS WHETHER SLOPE HAS ROLLED OVER BEYOND VERTICAL BELOW ROLL}
VAR
TOTAL:REAL;

BEGIN
TOTAL:=ALPHA+THETA1+THETA2;
IF TOTAL>90.0 THEN
   BEGIN
   TOTAL:=180.0 - TOTAL;
   WRITELN('**** WARNING SLOPE IS OVERHUNG BELOW ROLL');
   WRITELN('**** WARNING SLOPE IS    ',TOTAL:6:2);
   WRITELN(LST,'**** WARNING SLOPE IS OVERHUNG BELOW ROLL');
   WRITELN(LST,'**** WARNING SLOPE IS    ',TOTAL:6:2);
   END;
END;{PROCEDURE}
{************************************************************************}

PROCEDURE THETCALC;
{CALCULATES THETA1 AND THETA2 WITH BLOCK LENGTHS FROM ANGLUAR INPUT}
{CALCULATES XPAB,XQAB,ETC FROM GEOMETRY}
VAR
D,R:REAL;
BEGIN
```

```
R:=RADIUS;
THETA1R:=THETA1*PI/180.0;
THETA2R:=THETA2*PI/180.0;
SLOPE_CHECK;
IF (MODE=1) THEN
BEGIN
  L1:=RADIUS*THETA1R;
END;
L2:=RADIUS*THETA2R;
{CALC XPAB AND XQAB}
IF (MODE=1) THEN
BEGIN
XPAB:=(R+T)-R*COS(THETA1R);
XQAB:=R*SIN(THETA1R);
END;
IF (MODE=3) THEN
BEGIN
  XPAB:=T;
  XQAB:=L1;
END;
{CALC XP3B AND XQ3B}
XP3B:=(R+T)-R*COS(THETA2R);
XQ3B:=R*SIN(THETA2R);
END;
{*******************************************************************}

PROCEDURE INPUT;
VAR
  TOTAL:REAL;
LABEL  PRINTT;

   BEGIN
   {INPUT ASKS FOR THE FOLLOWING INFORMATION:
      ALPHA - ANGLE OF THE SLOPE ABOVE THE FOLD
      T     - THICKNESS OF SLAB
      METHOD OF INPUT - VIA RADIUS OF CURVATURE
                        RADIUS,ANGLE1,ANGLE2,CALCULATES THETA1 AND THETA2 OR
                     - VIA DEFINED THETA1 AND THETA2
      UNIT WEIGHTS  GAMMAW AND GAMMAR
      VERTICAL DIS-TANCE OF PHREATIC SURFACE ABOVE (+) OR BELOW (-) POINT A
      REFLECTED TO THE INNER SURFACE  -  WATD
      EXTERNAL FORCES D1 AND D2. BETAD1 AND BETAD2
      PHI AND C OF THE CROSS JOINTS FOR CHECKING PURPOSES
      }

      IF (INPUTFLAG=2) THEN GOTO PRINTT;
      D1:=0.;D2:=0.;BETAD1:=0.;BETAD2:=0.0;
      FOR I:=1 TO 5 DO BEGIN
      WRITELN;
      END;
   WRITELN('                  ANALYSIS OF CURVED SLAB ON SLOPE');
   WRITELN;WRITELN;
   WRITELN('                    (C) COPYRIGHT 1986 D.S. CAVERS');
   WRITELN;WRITELN;
   REPEAT
      WRITELN('DO YOU WISH TO INPUT PREVIOUS DATA FROM DISC? <Y/N>');
      READLN(ANSWER);
      UNTIL ANSWER IN ['Y','N'];
   IF ANSWER = 'Y'
        THEN READDISC
```

```
ELSE BEGIN
CLRSCR;
WRITELN('                  ANALYSIS OF CURVED SLAB ON SLOPE');
WRITELN('                    (C) COPYRIGHT 1986 D.S. CAVERS');
WRITELN;WRITELN;
WRITELN;WRITELN;
WRITELN('INPUT TITLE - ONE LINE TO 80 CHARS');
READLN(TITLE);
WRITELN;WRITE('INPUT SLAB THICKNESS  ');READLN(T);
WRITELN;WRITE('INPUT SLOPE ANGLE ABOVE ROLL  ');READLN(ALPHA);
WRITELN;WRITELN('INPUT UNIT WEIGHTS OF ROCK & WATER   ');
WRITE('USE SPACE TO SEPARATE   ');
READLN(GAMMAR,GAMMAW);
DRYFLAG:=0;
WRITELN;WRITE('IS SLOPE DRY <Y OR N>?');
READLN(ANSWER);
   IF ANSWER='N'THEN
   BEGIN
   DRYFLAG:=1;
   WRITELN;
   WRITELN('INPUT VERTICAL DISTANCE OF WATER WITH RESPECT');
   WRITE('TO REFLECTED LOWER HINGE POINT (+ ABOVE) ');
   READLN(WATD);
   END
ELSE
   BEGIN
   WRITELN;WRITELN('GAMMAW SET TO ZERO');
   GAMMAW:=0.0;
   END;
REPEAT
   WRITELN;WRITE('ARE THERE EXTERNAL FORCES? <Y,N>  ');
   READLN(ANSWER);
   UNTIL ANSWER IN ['Y','N'];
   IF ANSWER = 'Y' THEN BEGIN
      WRITELN;WRITELN('INPUT VALUES FOR D1 AND D2:<D1 D2>  ');
      WRITE('USE SPACE TO SEPARATE   ');
      READLN(D1,D2);WRITELN;
      WRITELN('INPUT VALUES FOR BETAD1 AND BETAD2 <B1,B2>:   ');
      WRITE('USE SPACE TO SEPARATE   ');
      READLN(BETAD1,BETAD2);
      BETAD1R:=BETAD1*PI/360.0;
      BETAD2R:=BETAD2*PI/360.0;
      END;
   WRITELN;
   WRITELN('INPUT VALUES FOR PHI AND C FOR CROSS JOINTS <PHI & C>')
   WRITE('USE SPACE TO SEPARATE   ');
   READLN(PHI,C);
   CLRSCR;
   REPEAT
      WRITELN;WRITELN('   DO YOU WISH TO INPUT VIA:');
      WRITELN('         1)  RADIUS OF CURVATURE AND ARCS DISTANCES,
      WRITELN('         2)  DEFINE ALL INPUT CONDITIONS');
      WRITELN('   NOTE THAT FOR OPTION 1 ALL CALCS ARE DONE FOR YOU
      WRITELN;WRITE('   CHOOSE 1 OR 2:  ');
      READLN(ANSWER);
   UNTIL ANSWER IN ['1','2'];
   IF ANSWER = '1'
      THEN BEGIN
      MODE:=1;
      WRITELN;WRITE('INPUT VALUE FOR RADIUS OF CURVATURE:  ');
```

```
     READLN(RADIUS);
     WRITELN;WRITE('INPUT VALUE FOR SUBTENDED ANGLES:');
     WRITELN(' <THETA1 & THETA2>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(THETA1,THETA2);
     THETA1R:=DEG_RAD(THETA1);
     THETA2R:=DEG_RAD(THETA2);
     SLOPE_CHECK;
     SLOPE_CHECK;
     THETCALC;
     WEIGHTS;
     GEOM;
     PORPRES;
     END
ELSE BEGIN
     MODE:=2;
     WRITELN;WRITE('INPUT VALUE FOR ANGLES THETA1 AND THETA2');
     WRITELN('  <THETA1,THETA2>:   ');
     READLN(THETA1,THETA2);
     SLOPE_CHECK;
     WRITELN;WRITE('INPUT VALUES FOR LENGTHS OF BLOCKS 1 AND 2');
     WRITELN('  <L1 & L2>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(L1,L2);
     W1:=L1*T*GAMMAR;W2:=L2*T*GAMMAR;
     WRITELN;WRITE('W1=    ',W1,'W2=    ',W2);
     WRITELN;WRITE('INPUT VALUES FOR MOMENT ARMS FOR W1 AND W2');
     WRITELN('  <XW1B & XW2B>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(XW1B,XW2B);
     WRITELN;WRITE('INPUT VALUES WATER FORCES FOR BLOCKS 1 AND 2')
     WRITELN('  <U1 & U2>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(U1,U2);
     WRITELN;WRITE('INPUT VALUES FOR MOMENT ARMS FOR WATER FORCES'
     WRITELN('  <XU1B & XU2B>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(XU1B,XU2B);
     WRITELN;WRITE('INPUT VALUES FOR ANGLES BETAU1 AND BETAU2');
     WRITELN(' FOR WATER FORCES  <BETAU1 & BETAU2>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(BETAU1,BETAU2);
     BETAU1R:=BETAU1*PI/180.0;
     BETAU2R:=BETAU2*PI/180.0;

     WRITELN;WRITE('INPUT VALUES FOR MOMENT ARMS FOR FORCES');
     WRITELN('  <XPAB & XQAB>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(XPAB,XQAB);
     WRITELN;WRITE('INPUT VALUES FOR MOMENT ARMS FOR FORCES');
     WRITELN('  <XP3B & XQ3B>:   ');
     WRITE('USE SPACE TO SEPARATE    ');
     READLN(XP3B,XQ3B);
     END;
  END;
  {END OF ALTERNATE INPUT INSTEAD OF DISC}

  PRINTT:
  CLRSCR;
  REPEAT
```

```
    WRITELN;WRITELN('IS PRINTER ON FOR DATA ECHO? <Y OR N>');
    READLN(ANSWER);
 UNTIL ANSWER IN ['Y'];
 WRITELN(LST);
 WRITELN(LST);
 WRITELN(LST);
 WRITELN(LST);
 WRITELN(LST);
 WRITELN(LST,^N,TITLE);
 WRITELN(LST,^N,'  THREE HINGED BEAM IN BUCKLING MODE');
 GETDATE;TIMEI;
 FOR I:=1 TO 5 DO BEGIN WRITELN(LST); END;
    WRITELN(LST,'MODE                     =    ',MODE:2);
    WRITELN(LST);
    WRITELN(LST,'THICKNESS OF SLAB  =      ',T:6:2);
    WRITELN(LST,'SLOPE ABOVE ROLL   =      ',ALPHA:6:2);
    TOTAL:=RAD_DEG(ALPHAR+THETA1R+THETA2R);
    IF ((MODE = 1) OR (MODE = 3)) THEN
    BEGIN
      WRITELN(LST,'SLOPE BELOW ROLL   =      ',TOTAL:6:2);
    END;
    WRITELN(LST,'GAMMA ROCK         =      ',GAMMAR:6:2);
    WRITELN(LST,'GAMMA WATER        =      ',GAMMAW:6:2);
    WRITELN(LST,'VERTICAL WATER DIST=      ',WATD:6:2);
    IF(DRYFLAG=0 AND INPUTFLAG=1)  THEN
       WRITELN(LST,'SLOPE WAS INPUT AS DRY');
    IF ((D1<>0.0) OR (D2<>0.0)) THEN BEGIN
       WRITELN(LST);

       WRITELN(LST,'EXTERNAL FORCES:');
       WRITELN(LST,'      D1           =      ',D1:9);
       WRITELN(LST,'      D2           =      ',D2:9);
       WRITELN(LST,'      BETAD1       =      ',RAD_DEG(BETAD1R):6
       WRITELN(LST,'      BETAD2       =      ',RAD_DEG(BETAD2R):6
       WRITELN(LST,'      XD1B         =      ',XD1B:6:2);
       WRITELN(LST,'      XD2B         =      ',XD2B:6:2);

    END;
    WRITELN(LST);
    WRITELN(LST,'PHI AND C FOR CROSS JOINTS:');
    WRITELN(LST,'      PHI          =    ',RAD_DEG(PHIR):6:2);
    WRITELN(LST,'      C            =    ',C:9);
    WRITELN(LST);
    IF MODE = 1
       THEN BEGIN
       WRITELN(LST,'RADIUS OF CURVATURE=    ',RADIUS:8:3);
       WRITELN(LST,'SUBTENDED ANGLES:');
       WRITELN(LST,'      THETA1       =    ',RAD_DEG(THETA1R):6:
       WRITELN(LST,'      THETA2       =    ',RAD_DEG(THETA2R):6:
    END;
    IF MODE=3 THEN
    BEGIN
       WRITELN(LST,'RADIUS OF CURVATURE=    ',RADIUS:8:3);
       WRITELN(LST);
       WRITELN(LST,'INPUTTED THETA ANGLES:');
       WRITELN(LST,'      THETA1       =    ',RAD_DEG(THETA1R):6:
       WRITELN(LST,'      THETA2       =    ',RAD_DEG(THETA2R):6:
       WRITELN(LST);
       WRITELN(LST,'INPUTTED BLOCK LENGTHS:');
       WRITELN(LST,'      LENGTH 1     =    ',L1:6:2);
      END;
      IF(MODE=2) THEN
      BEGIN
         WRITELN(LST);
         WRITELN(LST,'INPUTTED THETA ANGLES:');
         WRITELN(LST,'     THETA1       =    ',RAD_DEG(THETA1R):6:
         WRITELN(LST,'     THETA2       =    ',RAD_DEG(THETA2R):6:
         WRITELN(LST);
         WRITELN(LST,'INPUTTED BLOCK LENGTHS:');
         WRITELN(LST,'     LENGTH 1     =    ',L1:6:2);
         WRITELN(LST,'     LENGTH 2     =    ',L2:6:2);
         WRITELN(LST,'INPUTTED WT MOM ARMS:');
         WRITELN(LST,'      XW1B         =    ',XW1B:6:2);
         WRITELN(LST,'      XW2B         =    ',XW2B:6:2);
         WRITELN(LST,'INPUTTED WATER PRESSURE FORCES:');
         WRITELN(LST,'      U1           =    ',U1:9);
         WRITELN(LST,'      U2           =    ',U2:9);
         WRITELN(LST,'INPUTTED WATER MOM ARMS:');
         WRITELN(LST,'      XU1B         =    ',XU1B:6:2);
         WRITELN(LST,'      XU2B         =    ',XU2B:6:2);
         WRITELN(LST);
         WRITELN(LST,'INPUTTED BETA ANGLES:');
         WRITELN(LST,'     BETAU1       =    ',BETAU1:6:2);
         WRITELN(LST,'     BETAU2       =    ',BETAU2:6:2);
         WRITELN(LST);
         WRITELN(LST,'INPUTTED FORCE MOM ARMS:');
         WRITELN(LST,'      XPAB         =    ',XPAB:6:2);
         WRITELN(LST,'      XQAB         =    ',XQAB:6:2);
         WRITELN(LST,'      XP3B         =    ',XP3B:6:2);
         WRITELN(LST,'      XQ3B         =    ',XQ3B:6:2);

      END;
      END;{PROCEDURE}
      {**************************************************}
      PROCEDURE DISCSAVE;
      LABEL BYPASS;
      BEGIN

  CLRSCR;
  IF INPUTFLAG=2 THEN
  BEGIN
    ANSWER:='Y';
    GOTO BYPASS;
  END;

  REPEAT
     WRITELN;WRITELN;WRITE('DO YOU WISH TO SAVE DATA TO DISC?');
     WRITELN(' <Y OR N>  ');
     READLN(ANSWER);
  UNTIL ANSWER IN ['Y','N'];
BYPASS:
  IF ANSWER ='Y'
     THEN BEGIN
     WRITE('INPUT DISC AND FILENAME:    ');
     READLN(FILENAME);
     ASSIGN(FILEV,FILENAME);
     REWRITE(FILEV);
     WRITELN(FILEV,TITLE);
     WRITELN(FILEV,T);
     WRITELN(FILEV,ALPHA);
```

```
                    WRITELN(FILEV,GAMMAR);
                    WRITELN(FILEV,GAMMAW);
                    WRITELN(FILEV,WATD);
                    WRITELN(FILEV,D1);
                    WRITELN(FILEV,D2);
                    WRITELN(FILEV,BETAD1);
                    WRITELN(FILEV,BETAD2);
                    WRITELN(XD1B);
                    WRITELN(XD2B);
                    WRITELN(FILEV,PHI);
                    WRITELN(FILEV,C);
                    WRITELN(FILEV,MODE);
                    IF((MODE =1) OR (MODE=3))
                    THEN BEGIN
                       WRITELN(FILEV,RADIUS);
                       WRITELN(FILEV,RAD_DEG(THETA1R));
                       WRITELN(FILEV,RAD_DEG(THETA2R));
                    END;
                    IF ((MODE=2) OR (MODE=3)) THEN
                    BEGIN
                       WRITELN(FILEV,THETA1);
                       WRITELN(FILEV,THETA2);
                       WRITELN(FILEV,L1);
                       WRITELN(FILEV,L2);
                       WRITELN(FILEV,W1);
                       WRITELN(FILEV,W2);
                       WRITELN(FILEV,XW1B);
                       WRITELN(FILEV,XW2B);
                       WRITELN(FILEV,U1);
                       WRITELN(FILEV,U2);
                       WRITELN(FILEV,XU1B);
                       WRITELN(FILEV,XU2B);
                       WRITELN(FILEV,BETAU1);
                       WRITELN(FILEV,BETAU2);
                       WRITELN(FILEV,XPAB);
                       WRITELN(FILEV,XQAB);
                       WRITELN(FILEV,XP3B);
                       WRITELN(FILEV,XQ3B);
                       END;
                 END;{DISC OUTPUT}
   CLOSE(FILEV);
   END;{PROCEDURE}

{*****************************************************************
PROCEDURE CONV;                                                  *}
VAR
   CONSTT:REAL;
BEGIN
   CONSTT:=PI/180.;
   THETA1R:=THETA1*CONSTT;
   THETA2R:=THETA2*CONSTT;
   ALPHAR:=ALPHA*CONSTT;
   BETAD1R:=BETAD1*CONSTT;
   BETAD2R:=BETAD2*CONSTT;
   BETAU1R:=BETAU1*CONSTT;
   BETAU2R:=BETAU2*CONSTT;
   PHIR:=PHI*CONSTT;
END;
{*****************************************************************
PROCEDURE MATA_PRINT;                                            *}
```

```
{PRINTS OUT MATRIX A IF REQUIRED}
BEGIN
   FOR I:=1 TO 4 DO
      BEGIN
      WRITELN(LST);
      FOR J:=1 TO 4 DO
         BEGIN
         WRITE(LST,A[I,J]);
         END;
      END;
END;
{*********************************************************************}
PROCEDURE QUESTIONA;
BEGIN
REPEAT
   WRITELN;WRITE('DO YOU WISH TO SEE MATRIX A? <Y/N>    ');
   READLN(ANSWER);
   UNTIL ANSWER IN ['Y','N'];

IF ANSWER='Y' THEN
BEGIN
  WRITELN(LST);WRITELN(LST,'    MATRIX A:');
  MATA_PRINT;
END;
END;{PROCEDURE}

{***********************************************************************}
PROCEDURE MATB_PRINT;
{PRINTS OUT MATRIX B IF REQUIRED}
BEGIN
   FOR I:=1 TO 4 DO
      BEGIN
      WRITELN(LST);
      WRITELN(LST,B[I]);
      WRITELN(LST);
      END;
END;
{***************************************************************************}
PROCEDURE QUESTIONB;
BEGIN
REPEAT
   WRITELN;WRITE('DO YOU WISH TO SEE MATRIX B? <Y/N>    ');
   READLN(ANSWER);
   UNTIL ANSWER IN ['Y','N'];

IF ANSWER='Y' THEN
BEGIN
  WRITELN(LST);WRITELN(LST,'    MATRIX B:');
  MATB_PRINT;
END;
END;
{*****************************************************************************}
PROCEDURE SETUP(ASK:BOOLEAN);

{SETS UP EQUATIONS FOR 4X4 PARTITIONED MATRIX}
BEGIN
   A[1,1]:=-COS(THETA1R);
   A[1,2]:=-SIN(THETA1R);
   A[1,3]:=1.0;
   A[1,4]:=0.0;
   A[2,1]:=-A[1,2];
   A[2,2]:=A[1,1];
   A[2,3]:= -XPAB/XQAB;
   A[2,4]:=0.0;
   A[3,1]:=COS(THETA1R);
   A[3,2]:=SIN(THETA1R);
   A[3,3]:=0.0;
   A[3,4]:= -(COS(THETA1R+THETA2R) +XP3B*SIN(THETA1R+THETA2R)/XQ3B);
   A[4,1]:=-SIN(THETA1R);
   A[4,2]:=COS(THETA1R);
   A[4,3]:=0.0;
   A[4,4]:= (SIN(THETA1R+THETA2R) -XP3B*COS(THETA1R+THETA2R)/XQ3B);
   {NOW EQUATE MATRIX AA TO A TO SAVE ORIGINAL MATRIX}
   IF ASK THEN QUESTIONA;

    FOR I:=1 TO 4 DO
    FOR J:=1 TO 4 DO
    BEGIN
       AA[I,J]:=A[I,J];
       END;
{COEFFICIENTS IN THE ABOVE ARE IN THE ORDER:P1,Q1,PA,P3}

{NOW SET UP THE MATRIX FOR B CORRESPONDING TO THE ABOVE}

   B[1] :=-W1*SIN(ALPHAR)+D1*COS(BETAD1R+ALPHAR)-U1*COS(BETAU1R +ALPHAR);
   B[1]:=B[1]+D1DIST*COS(PI/2.0-THETA1R);
   {PERTURBING FORCE}

   B2:=W1*COS(ALPHAR)+D1*SIN(BETAD1R+ALPHAR)-U1*SIN(BETAU1R+ALPHAR);
   {LINE FOLLOWING ADDED JUL 28,86 TO ALLOW FOR PERTURBING FORCE}
   B2:=B2+D1DIST*SIN(PI/2.0-THETA1R);
   B3:=-W1*XW1B-D1*XD1B+U1*XU1B;
   B[2]:=B2+B3/XQAB;

   B4:=-W2*SIN(ALPHAR)+D2*COS(BETAD2R+ALPHAR)-U2*COS(BETAU2R+ALPHAR);
   B6:=W2*XW2B+D2*XD2B-U2*XU2B;
   B[3]:=B4-B6*SIN(THETA1R+THETA2R)/XQ3B;

   B5:=W2*COS(ALPHAR)+D2*SIN(BETAD2R+ALPHAR)-U2*SIN(BETAU2R+ALPHAR);
   B5:=B5+D2DIST*SIN(PI/2.0-THETA1R);
   B[4]:=B5-B6*COS(THETA1R+THETA2R)/XQ3B;
   IF ASK THEN QUESTIONB;

END;{SETUP}
{****************************************************************}
{$I MATINV }
> {************************************************************}
>
>
> PROCEDURE MATINV;
>
>
> {       SUBROUTINE MATINV(N,IND,MAX)}
> {       FROM GERSTLE  BASIC STRUCTURAL ANALYSIS}
> {
>         THIS SUBROUTINE CALCULATES A INV
>         A = A INVERSE
>         WHERE A (ORDER N*N) IS STORED IN DIMENSION OF MAX ROWS
>         AND MUST MATCH THE NUMBER OF ROWS FOR WHICH IT IS DIMENSIONED
>         IN MAIN PROGRAM
> }
> VAR
>    N,II,I,IR,JC:INTEGER;
>    AMAX,TEMP,TE,PIVOT:REAL;
> {   A:ARRAY[1..4,1..4] OF REAL;}
>    IND:ARRAY[1..4,1..2] OF INTEGER;
> LABEL
>    DODGE,551,556,JEND,IEND,568,PROCEND,559;
>
> BEGIN
> N:=4;
> FOR I:=1 TO N DO BEGIN
>   IND[I,1]:= 0;
>   IND[I,2]:=0;
>   END;
> II:=0;
> 551:
>      AMAX:= -1.0;
>   FOR  I:=1 TO N DO
>   BEGIN
>   IF (IND[I,1] <> 0) THEN GOTO IEND;
>   FOR J:=1 TO N DO
>      BEGIN
>      IF(IND[J,1] <> 0) THEN GOTO JEND;
>      TEMP := ABS(A[I,J]);
>      TE := TEMP - AMAX;
>      IF (TE <= 0) THEN GOTO JEND;
>      IR := I;
>      JC := J;
>      AMAX  := TEMP;
>   JEND:
>   END;
>   IEND:
>   END;
>       IF (AMAX = 0.0) THEN BEGIN
>   WRITELN;WRITELN('     ZERO PIVOT IN MATRIX, EXECUTION STOPPED');
>   HALT;END;
>       IF(AMAX < 0.0) THEN GOTO 556;
>
>       IND[JC,1]:=IR;
> {     INTERCHANGE ROWS}
>       IF (IR = JC) THEN GOTO 559;
>       FOR J:=1 TO N DO
>   BEGIN
>   TEMP := A[IR,J];
>   A[IR,J] := A[JC,J];
>   A[JC,J] := TEMP;
>   END;
>       II:=II + 1;
>       IND[II,2]:= JC;
> {     INVERSION BY  GAUSS JORDAN METHOD}
>
>   559:
>        PIVOT := A[JC,JC];
>        A[JC,JC] := 1.0;
>        PIVOT := 1.0/PIVOT;
>
>        FOR J:=1 TO N DO
>    BEGIN
>    A[JC,J] := A[JC,J] * PIVOT;
>    END;
>        FOR I:=1 TO N DO
>    BEGIN
>    IF(I = JC) THEN GOTO DODGE;
>       TEMP := A[I,JC];
>       A[I,JC] := 0.;
>       FOR J:=1 TO N DO BEGIN
>   A[I,J] := A[I,J] - A[JC,J] * TEMP;
>   END;{J}
>     DODGE:
>    END;{I}
>       GOTO 551;
> {     REARRANGE ROWS}
>   568:
>       JC := IND[II,2];
>       IR := IND[JC,1];
>       FOR I:=1 TO N DO BEGIN
>   TEMP := A[I,IR];
>   A[I,IR] := A[I,JC];
>   A[I,JC] := TEMP;
>   END;
>       II :=II - 1;
> 556:
> IF (II=0) THEN GOTO PROCEND;
> GOTO 568;
> PROCEND:
>       END;
>       {***********************************************************}
{*****************************************************************}
PROCEDURE MATMULT(A,AA:MATRIX;VAR ANS:MATRIX);
{MULTIPLIES A AND AA TO CHECK THAT IDENTITY MATRIX IS OBTAINED}
VAR
   ANSRES:REAL;
   K:INTEGER;
BEGIN
   FOR I:=1 TO 4 DO BEGIN
      FOR J:=1 TO 4 DO BEGIN
      ANSRES:=0.0;
         FOR K:=1 TO 4 DO BEGIN
         ANSRES:=ANSRES + AA[I,K]*A[K,J];
         END;
      ANS[I,J]:=ANSRES;
      END;
   END;
END;
{***************************************************************}

PROCEDURE CHECK(ASK:BOOLEAN);
{CHECKS THAT IDENTITY MATRIX IS OBTAINED}

BEGIN
WRITELN;WRITELN('CHECKING THAT IDENTITY MATRIX IS VALID');
ANSWARN:=0;
FOR I:=1 TO 4 DO
FOR J:=1 TO 4 DO
   BEGIN
   IF I=J THEN
   BEGIN
      IF ABS(ANS[I,J]-1.0) > 0.001 THEN
      BEGIN
```

```
         WRITELN('IDENTITY MATRIX HAS A VALUE ON THE DIAGONAL');
         WRITELN('WHICH IS SIGNIFICANTLY DIFFERENT FROM 1.0');
         WRITELN;
         WRITELN('THE VALUE OF ANS[',I:1,',',J:1,'] IS    ',ANS[I,J]);
      END;
   END;
   END;
   IF I<>J THEN BEGIN
       IF ABS(ANS[I,J]) > 0.001 THEN BEGIN
            WRITELN('IDENTITY MATRIX HAS A VALUE OFF THE DIAGONAL');
            WRITELN('WHICH IS SIGNIFICANTLY DIFFERENT FROM 0.0');
            WRITELN;
            WRITELN('THE VALUE OF ANS[',I:1,',',J:1,'] IS    ',ANS[I,J]);
       END;
   END;
   IF ASK THEN BEGIN
      REPEAT
         WRITELN;WRITELN('DO YOU WISH TO SEE THE IDENTITIY MATRIX <Y,N>?');
         READLN(ANSWER);
         UNTIL ANSWER IN ['Y','N'];
         IF ANSWER = 'Y' THEN BEGIN
            CLRSCR;
            WRITELN;WRITELN;WRITELN;WRITELN;
            FOR I:= 1 TO 4 DO BEGIN
               WRITE('          ');
               FOR J:= 1 TO 4 DO BEGIN
                  WRITE(ANS[I,J]:8:4);
               END;
            WRITELN;
            END;
         END;
         REPEAT
            WRITELN;WRITELN('DO YOU WISH TO SEE THE INVERTED MATRIX <Y,N>?');
            READLN(ANSWER);
         UNTIL ANSWER IN ['Y','N'];
         IF ANSWER='Y' THEN WRITELN(LST,'INVERTED MATRIX:');
         IF ANSWER = 'Y' THEN MATA_PRINT;
      END;
   END;
{****************************************************************}
PROCEDURE CALC_DATA_PRINT;
{PRINTS THE RESULTS OF CALCULATIONS }
LABEL BYPASS;

BEGIN
  IF (INPUTFLAG=2) THEN GOTO BYPASS;
  WRITELN;WRITELN('CALCULATIONS ARE COMPLETE');
  WRITELN;WRITELN('WRITING RESULTS TO PRINTER');
  BYPASS:
  GETDATE;TIMEI;
  WRITELN(LST);WRITELN(LST,'THE FOLLOWING DATA HAS BEEN CALCULATED:');
  WRITELN(LST);
  IF ((MODE=1) OR (MODE=3)) THEN
  BEGIN
    WRITELN(LST,'CALCULATED BLOCK LENGTHS:');
    WRITELN(LST,'      LENGTH 1     =     ',L1:8:3);
    WRITELN(LST,'      LENGTH 2     =     ',L2:8:3);
  END;
  WRITELN(LST,'CALCULATED BLOCK WEIGHTS:');
  WRITELN(LST,'      W1           =     ',W1:8:3);
  WRITELN(LST,'      W2           =    ',W2:8:3);
  IF ((MODE=1) OR (MODE=3)) THEN
  BEGIN
  WRITELN(LST,'CALCULATED WT MOM ARMS:');
  WRITELN(LST,'       XW1B          =   ',XW1B:8:3);
  WRITELN(LST,'       XW2B          =   ',XW2B:8:3);
  WRITELN(LST,'CALCULATED WATER PRESSURE FORCES:');
  WRITELN(LST,'      U1             =   ',U1:9);
  WRITELN(LST,'      U2             =   ',U2:9);
  WRITELN(LST,'CALCULATED WATER MOM ARMS:');
  WRITELN(LST,'       XU1B          =   ',XU1B:8:3);
  WRITELN(LST,'       XU2B          =   ',XU2B:8:3);
  BETAU1:=RAD_DEG(BETAU1R);
  BETAU2:=RAD_DEG(BETAU2R);
  WRITELN(LST,'CALCULATED BETA ANGLES:');
  WRITELN(LST,'      BETAU1         =   ',BETAU1:8:3);
  WRITELN(LST,'      BETAU2         =   ',BETAU2:8:3);
  WRITELN(LST,'CALCULATED FORCE MOM ARMS:');
  WRITELN(LST,'       XPAB          =   ',XPAB:8:3);
  WRITELN(LST,'       XQAB          =   ',XQAB:8:3);
  WRITELN(LST,'       XP3B          =   ',XP3B:8:3);
  WRITELN(LST,'       XQ3B          =   ',XQ3B:8:3);
  END;
  END;
  {***********************************************************}

PROCEDURE RESULTS_MULT;
{MULTIPLIES INVERTED MATRIX BY COEFFICIENTS TO GET ANSWERES}
{A IS THE INVERTED MATRIX AFTER MATINV}
{B IS THE COEFFICIENT MATRIX}
VAR
    ANSRES:REAL;

BEGIN
   FOR I:=1 TO 4 DO
   BEGIN
   ANSRES:=0.0;
      FOR J:= 1 TO 4 DO
      BEGIN
      ANSRES:=ANSRES + A[I,J]*B[J];
      END;
   OUTPUT[I]:=ANSRES;
   END;
P1:=OUTPUT[1];
Q1:=OUTPUT[2];
PA:=OUTPUT[3];
P3:=OUTPUT[4];
QA:=(B3 + XPAB*PA)/XQAB;
Q3:=(-B6 + XP3B*P3)/XQ3B;
END;
{*******************************************************************}
FUNCTION FSAFE(XX,YY:REAL):REAL;
VAR
   SHEAR_RES:REAL;
BEGIN
SHEAR_RES:=XX*TAN(PHIR) + T*C;
FSAFE:=SHEAR_RES/YY;
END;
{*******************************************************************}
```

```
PROCEDURE RESULTS_PRINT;
{PRINTS OUT RESULTS OF CALCULATIONS}
BEGIN
GETDATE;TIMEI;
WRITELN(LST,^L,^J,^J);
WRITELN(LST,^N,TITLE);
WRITELN(LST,^N,'THREE HINGED CURVED BEAM IN BUCKLING MODE');
WRITELN(LST,^j^j^j);
WRITELN(LST,^N'RESULTS FOR TOP HINGE POINT:',^J);
WRITELN(LST,'           NORMAL FORCE (PA):    ',PA:9);
WRITELN(LST,'           SHEAR  FORCE (QA):    ',QA:9);
WRITELN(LST,^N,'RESULTS FOR MID HINGE POINT:',^J);
WRITELN(LST,'           NORMAL FORCE (P1):    ',P1:9);
WRITELN(LST,'           SHEAR  FORCE (Q1):    ',Q1:9);
WRITELN(LST,^N,'RESULTS FOR LOW HINGE POINT:',^J);
WRITELN(LST,'           NORMAL FORCE (P3):    ',P3:9);
WRITELN(LST,'           SHEAR  FORCE (Q3):    ',Q3:9);
WRITELN(LST);WRITELN(LST);
WRITELN(LST,^N,'RATIOS OF SHEAR AND NORMAL FORCES:');
WRITELN(LST,^N,'         P/Q     FS');
FS:=FSAFE(PA,QA);
WRITELN(LST,'UPPER HINGE');
WRITELN(LST,'               ',P1/Q1:8:3,'        ',FS:8:3);
FS:=FSAFE(P1,Q1);
WRITELN(LST,'MIDDLE HINGE');
WRITELN(LST,'               ',PA/QA:8:3,'        ',FS:8:3);
FS:=FSAFE(P3,Q3);
WRITELN(LST,'LOWER HINGE');
WRITELN(LST,'               ',P3/Q3:8:3,'        ',FS:8:3);
WRITELN(LST,^j^j^j);
IF (INPUTFLAG=1) THEN
BEGIN
  WRITELN('   END OF PROGRAM - EXECUTION STOPPED');
  WRITELN(LST,'   END OF PROGRAM - EXECUTION STOPPED');
END;
END;
{*****************************************************}
PROCEDURE PERTURB;
{PUTS PERTURBING FORCE OF F(W1+W2)_ ON CENTER JOINT
TO ASSESS STABILITY CONDITIONS}

VAR
  NCOUNT,NN:INTEGER;
  D1RES,P1OLD,DIVV:REAL;
  ASK:BOOLEAN;


BEGIN
NCOUNT:=0;
D1DIST:=0.0;
D2DIST:=0.0;
NN:=0;
DIVV:=0.50;
WRITELN(LST,^j^j);
WRITELN(LST,^N,TITLE);
WRITELN(LST,^N,'  THREE HINGED BEAM IN BUCKLING MODE');
GETDATE;TIMEI;
WRITELN(LST,^j^j^j);
WRITELN(LST,' FDISTURB       P1          Q1          PA          QA          P3
WRITELN(LST,(D1DIST+D2DIST):10,' ',P1:10,' ',Q1:10,' ',PA:10,' ',QA:10,' ',P3:1
{START PERTURBATION}
D1DIST:=-0.025*(W1+W2);
D2DIST:=D1DIST;

  ASK:=FALSE;
  D1RES:=D1DIST+D2DIST;
  P1OLD:=P1;
  REPEAT
    SETUP(ASK);
    MATINV;
    MATMULT(A,AA,ANS);
    CHECK(ASK);
    RESULTS_MULT;
    WRITELN(LST,(D1DIST+D2DIST):10,' ',P1:10,' ',Q1:10,' ',PA:10,' ',QA:10,' ',
    D1DIST:=D1DIST+D1RES/DIVV;
    NN:=NN+1;
    IF (NN>=10) THEN
    BEGIN
      NN:=0;
      DIVV:=DIVV/10.0;
    END;
    NCOUNT:=NCOUNT+1;
  UNTIL ((P1>0.0) OR (P1<P1OLD) OR (NCOUNT>=100));
  IF ((P1>0.0) AND (P1OLD<=0)) THEN
  BEGIN
    WRITELN(LST,^j^j^n,'SLOPE IS STABLE');
    WRITELN(LST,^J,'EXAMINE THE MAGNITUDE OF THE PERTURBING FORCES TO ');
    WRITELN(LST,'DETERMINE THE DEGREE OF STABILITY');
  END;
  IF ((P1>0.0) AND ((P1OLD>=0) AND (P1>P1OLD))) THEN
  BEGIN
      WRITELN(LST,^j^j^n,'SLOPE IS CONDITIONALLY STABLE-P1 IS MINIMUM');
      WRITELN(LST,^J,'EXAMINE THE MAGNITUDE OF THE PERTURBING FORCES TO ');
      WRITELN(LST,'DETERMINE THE DEGREE OF STABILITY');
  END;
  IF ((P1OLD>0.0) AND (P1<P1OLD)) THEN
  BEGIN
      WRITELN(LST,^j^j^n,'SLOPE IS CONDITIONALLY STABLE-P1 IS MAXIMUM');
      WRITELN(LST,^J,'EXAMINE THE MAGNITUDE OF THE PERTURBING FORCES TO ');
      WRITELN(LST,'DETERMINE THE DEGREE OF STABILITY');
  END;

  IF ((P1<P1OLD) AND (P1OLD<=0.0)) THEN
  BEGIN
    WRITELN(LST,^J^J^N,'SLOPE IS UNSTABLE');
  END;
  IF NCOUNT>=100 THEN
  BEGIN
    WRITELN(LST,^J^J,'NOCOUNT EXCEEDED MAXIMUM - CONDITIONS NOT SATISFIED');
  END;
 END;{PROCEDURE}
 {*****************************************************}
 PROCEDURE F2;{CALCULATES INPUT SCREEN FOR MODE 1 AND 2}
 BEGIN
 IF MODE=1 THEN
 BEGIN
   THETCALC;
   PORPRES;
   GEOM;
 END;
```

```
IF MODE=3 THEN
BEGIN
  IF ((THETA1R>0.001) OR (THETA1R<-0.001) OR (ABS(L1)<0.001)) THEN
  BEGIN
    GOTOXY(3,24);
    TEXTBACKGROUND(15); TEXTCOLOR(0);
    WRITE('THETA1R IS NOT 0.0 OR L1=0.0');
    WRITE(#7);
    DELAY(1000);
    WRITE(#7);
    GOTOXY(3,24);
    DELLINE;INSLINE;
    CASEFLAG:=TRUE;
    EXIT;
  END;
THETCALC;
PORPRES;
GEOM;
END;
WEIGHTS;
IF (CH=#60) THEN SCREENGEN;
CASEFLAG:=TRUE;
END;
{*************************************************************}
PROCEDURE F1;{PRINTS INPUT DATA}
BEGIN
CASEFLAG:=TRUE;
F2;
REPEAT
  TEXTCOLOR(0);TEXTBACKGROUND(15);
  GOTOXY(3,24); WRITE('DO YOU WISH TO PRINT DATA <Y,N>?');
  TEXTCOLOR(15);TEXTBACKGROUND(0);
  READ(ANSWER);
UNTIL ANSWER IN ['Y','N'];
IF ANSWER ='Y' THEN
BEGIN
  INPUT;{PRINTS INPUT DATA FOR SCREEN METHOD}
END;
REPEAT
  TEXTCOLOR(0);TEXTBACKGROUND(15);
  GOTOXY(3,24); WRITE('DO YOU WISH TO SAVE DATA <Y,N>?');
  TEXTCOLOR(15);TEXTBACKGROUND(0);
  READ(ANSWER);
UNTIL ANSWER IN ['Y','N'];
IF ANSWER ='Y' THEN
BEGIN
   DISCSAVE;
 END;
SCREENGEN;
END;
{**************************************************************}
PROCEDURE F3;
BEGIN
F2;
CASEFLAG:=TRUE;
END;
{**************************************************************}
PROCEDURE F4;{GENERATES OUTPUT SCREEN AND DOES CALCS}
VAR
  ASK:BOOLEAN;
```

```
BEGIN
CLRSCR;
ASK:=TRUE;
D1DIST:=0.0;
D2DIST:=0.0;
F2;
SLOPE_CHECK;
SETUP(ASK);
MATINV;
MATMULT(A,AA,ANS);
CHECK(ASK);
RESULTS_MULT;
PERTURB;

{REPEAT
  CLRSCR;GOTOXY(10,10);
  TEXTCOLOR(0);TEXTBACKGROUND(15);
  WRITE('DO YOU WISH TO PRINT RESULTS? <Y,N>  ');
  TEXTCOLOR(7);TEXTBACKGROUND(0);
  READLN(ANSWER);
UNTIL ANSWER IN ['Y','N'];
IF ANSWER='Y' THEN
BEGIN
  RESULTS_PRINT;
END;}

CASEFLAG:=TRUE;
SCREENGEN;
END;
{************************************************************}
PROCEDURE F5;
BEGIN
F2;
CALC_DATA_PRINT;
SCREENGEN;
END;
{************************************************************}

PROCEDURE F6;{RETURN TO DOS}
BEGIN
REPEAT;
  TEXTBACKGROUND(15);TEXTCOLOR(0);
  GOTOXY(3,24); WRITE('EXIT TO DOS <Y,N>');
  TEXTBACKGROUND(0);TEXTCOLOR(15);
  READLN(ANSWER);
UNTIL ANSWER IN ['Y','N'];
TEXTCOLOR(15);
IF ANSWER='N' THEN
BEGIN
  GOTOXY(3,24);
  DELLINE;INSLINE;
  CASEFLAG:=TRUE;
  EXIT;
END
ELSE
BEGIN
  CLRSCR;
  HALT;
END;{PROC}
END;
```

```
{************************************************************}

PROCEDURE KEYS;
{READS KEYBOARD AND MAKES DECISIONS}
TYPE
CHARSET=SET OF CHAR;
VAR
STR1,STR2:STRING[10];
CONTINUE:BOOLEAN;
N,CODE:INTEGER;
INPUTVAL:REAL;
LABEL BEG,WHILEEND;
VAR
NUMBERS:CHARSET;

BEGIN
WHILE KEYPRESSED READ(KBD,CH);
CONTINUE:=TRUE;
NUMBERS:=[#8,#13,#45,#46,#48..#57,#27];
BEG:
GOTOXY(XX,YY);
IF WHEREY=3 THEN
BEGIN
  TEXTBACKGROUND(7);TEXTCOLOR(0);
  WRITE('                                                  ');
  GOTOXY(XX,YY);
  TEXTBACKGROUND(0);TEXTCOLOR(15);
END;
IF WHEREY>=5 THEN
BEGIN
  TEXTBACKGROUND(7);TEXTCOLOR(0);
  WRITE('          ');
  GOTOXY(XX,YY);
  TEXTBACKGROUND(0);TEXTCOLOR(15);
END;
STR1:='          ';
REPEAT UNTIL KEYPRESSED;
  READ(KBD,CH);
  IF ((CH=#27) AND KEYPRESSED) THEN
  BEGIN
    READ(KBD,CH);
    CASEFLAG:=FALSE;
    CASE CH OF
      #59:  F1;
      #60:  F2;
      #61:  F3;
      #62:  F4;
      #63:  F5;
      #64:  F6;{RETURN TO DOS}
      #75:  LARR;
      #77:  RARR;
      #72:  UARR;
      #80:  DARR;
      ELSE WRITE(#7);
    END;
  IF CASEFLAG THEN
  BEGIN
    CASEFLAG:=FALSE;
    GOTO BEG;
  END;
```

```
END;

{GET TO HERE IF NOT A FUNCTION KEY}
CONTINUE:=TRUE;
{XX AND YY ARE CURSOR POSITIONS}

IF((YY>4) AND (NOT(CH IN NUMBERS))) THEN
BEGIN
  WRITE(#7);
  GOTO BEG;
END;

GOTOXY(XX,YY);
NN:=1;
INSERT(CH,STR1,NN);
WRITE(STR1);
CONTINUE:=TRUE;

IF YY=3 THEN
BEGIN
  DELETE(TITLE,1,80);
  INSERT(CH,TITLE,NN);
END;

  WHILE CONTINUE DO
  BEGIN
    REPEAT UNTIL KEYPRESSED;
    READ(KBD,CH);
    IF ((NOT(CH IN NUMBERS)AND (YY>=4))) THEN
    BEGIN
      WRITE(#7);
      GOTO WHILEEND;
    END;
    IF (CH= (#13)) THEN
    BEGIN
      CONTINUE:=FALSE;
      GOTO WHILEEND;
    END;
    IF CH=#8 THEN
    BEGIN
     IF NN<>1 THEN
     BEGIN
       DELETE(STR1,NN,1);
       GOTOXY(XX,YY);
       TEXTBACKGROUND(7);TEXTCOLOR(0);
       WRITE('             ');
       GOTOXY(XX,YY);
       WRITE(STR1);
       NN:=NN-1;
       GOTO WHILEEND;
     END
     ELSE
     BEGIN
       WRITE(#7);
       GOTO WHILEEND;
     END;
   END;
    IF (CH=(#27)) THEN
    BEGIN
      READ(KBD,CH);
      CASE CH OF
      #75:BEGIN CONTINUE:=FALSE;GOTO WHILEEND;END;
      #77:BEGIN CONTINUE:=FALSE;GOTO WHILEEND;END;
      #72:BEGIN CONTINUE:=FALSE;GOTO WHILEEND;END;
      #80:BEGIN CONTINUE:=FALSE;GOTO WHILEEND;END;
      ELSE  WRITE(#7);
      END;
      GOTO WHILEEND;
    END;

    IF (YY>4) THEN
    BEGIN
      NN:=NN+1;
      INSERT(CH,STR1,NN);
      TEXTBACKGROUND(7);TEXTCOLOR(0);
      GOTOXY(XX,YY);
      WRITE(STR1);
      TEXTBACKGROUND(0);TEXTCOLOR(15);
      GOTO WHILEEND;
    END;

    IF YY=3 THEN
    BEGIN
      nn:=nn+1;
      INSERT(CH,TITLE,NN);
      TEXTBACKGROUND(7);TEXTCOLOR(0);
      GOTOXY(XX+NN,YY);
      WRITE(CH);
      TEXTBACKGROUND(0);TEXTCOLOR(15);
      GOTO WHILEEND;
    END;
    WHILEEND:
  END;
  IF YY=3 THEN
  BEGIN
    GOTOXY(XX,YY);WRITE(TITLE);
    GOTO BEG;
  END;
  DELETE(STR1,NN+1,10);
  VAL(STR1,INPUTVAL,CODE);
  IF CODE<>0 THEN
  BEGIN
    GOTOXY(1,24);WRITE(#7);
    TEXTCOLOR(0);TEXTBACKGROUND(15);
    WRITE('  ERROR IN STRING POSITION ',CODE:2,'  RE-ENTER');
    TEXTCOLOR(7);TEXTBACKGROUND(0);
    GOTOXY(XX,YY);
    GOTO BEG;
  END;

VARL(XX,YY,VARFLAG);
CASE VARFLAG OF
1:  MODE:=ROUND(INPUTVAL);
2:  BEGIN ALPHAR:=DEG_RAD(INPUTVAL);ALPHA:=INPUTVAL;END;
3:  RADIUS:=INPUTVAL;
4:  BEGIN THETA1R:=DEG_RAD(INPUTVAL);THETA1:=INPUTVAL;END;
5:  BEGIN THETA2R:=DEG_RAD(INPUTVAL);THETA2:=INPUTVAL;END;
6:  GAMMAW:=INPUTVAL;
7:  GAMMAR:=INPUTVAL;
8:  WATD:=INPUTVAL;
```

```
9:  BEGIN PHIR:=DEG_RAD(INPUTVAL);PHI:=INPUTVAL;END;
10: C:=INPUTVAL;
11: XPAB:=INPUTVAL;
12: XQAB:=INPUTVAL;
13: XP3B:=INPUTVAL;
14: XQ3B:=INPUTVAL;
15: T:=INPUTVAL;
16: L1:=INPUTVAL;
17: L2:=INPUTVAL;
18: W1:=INPUTVAL;
19: W2:=INPUTVAL;
20: U1:=INPUTVAL;
21: U2:=INPUTVAL;
22: D1:=INPUTVAL;
23: D2:=INPUTVAL;
24: XW1B:=INPUTVAL;
25: XW2B:=INPUTVAL;
26: XU1B:=INPUTVAL;
27: XU2B:=INPUTVAL;
28: XD1B:=INPUTVAL;
29: XD2B:=INPUTVAL;
30: BEGIN BETAU1R:=DEG_RAD(INPUTVAL);BETAU1:=INPUTVAL;END;
31: BEGIN BETAU2R:=DEG_RAD(INPUTVAL);BETAU2:=INPUTVAL;END;
32: BEGIN BETAD1R:=DEG_RAD(INPUTVAL);BETAD1:=INPUTVAL;END;
33: BEGIN BETAD2R:=DEG_RAD(INPUTVAL);BETAD2:=INPUTVAL;END;
END;{CASE}
CASE CH OF
#75:LARR;
#77:RARR;
#72:UARR;
#80:DARR;
ELSE
XYWRITE(XX,YY);
END;
GOTO BEG;
END;
{************************************************************}

{BEGIN MAIN PROGRAM}
VAR
  ASK:BOOLEAN;
BEGIN
ZEROV;
N:=4;
INITIAL;
XX:=11;YY:=3;
ROWVAR:=3;COLVAR:=1;
IF INPUTFLAG=2 THEN
BEGIN
  SCREENGEN;
  KEYS;
END
ELSE
BEGIN
  CLRSCR;
  INPUT;
  DISCSAVE;
  CONV;
  IF MODE=1 THEN
  BEGIN
```

```
    WEIGHTS;
    GEOM;
    PORPRES;
    CALC_DATA_PRINT;
  END;
  SETUP(ASK);
  MATINV;
  MATMULT(A,AA,ANS);
  CHECK(ASK);{CHECKS THAT IDENTITIY MATRIX RESULTS}
  RESULTS_MULT;
  RESULTS_PRINT;
END;
END.
{*******************************************************}
```

APPENDIX C

STABILITY TABLES FOR THREE HINGE BUCKLING

C.1 GENERAL

The attached tables have been developed using program CURVBUK under Mode 3 (see Figure B-3) for three hinge buckling of curved slopes. The following assumptions were made in the analysis:

a) Failure mode was similar to Mode 3. Other modes were checked but were not critical.

b) Dry conditions.

c) Blocks remain intact.

d) For stable conditions, the critical value for L1 was not determined explicitly, but was assumed to be 5T.

The analysis was carried out for slopes of 40, 55 and 70° using radii of curvature of 10, 50, 100 and 300 m. Slab thicknesses (T) of 0.5, 1, 2, 3, 6 and 9 m where used. The rolls were assumed to be through an angle of theta2 (θ_2) varying from 10° to a maximum of 45°. The various values input into the analysis are shown on Figure B-1.

For each final result for a particular input data set several runs were made to find the critical value for L1 (length of block 1). This process is analogous to finding the critical failure surface in the case of conventional limit equilibrium analysis.

The following summary data is provided:

a) Stability tables for three hinge buckling (curved slopes).

b) Corresponding slab lengths for stability tables.

c) Driving force design charts.

Use of these materials is discussed in the following pages.

STABILITY TABLES FOR THREE HINGE BUCKLING

With reference to Table C-1:

θ_2 = Theta2
α = Alpha
R = Radius

For each combination of alpha, T, radius and theta2, the tables give the following:

Value of P_1 (no brackets) OR
Value of perturbing force (negative number in brackets).

An unbracketed number is a value for P_1, and represents the maximum P_1 (driving force) which may be applied to the top edge of the roll before failure. (See definition of P_1 on Figure B-1). This value may be correlated to driving force using Figures at the end of this Appendix.

Bracketed negative numbers indicate the following:

a) The slope is stable under all values of P_1.

b) The slope may be brought to limiting equilibrium by applying an outward force approximately equal to the absolute value of the perturbing force at the center hinge. This force value may be correlated to seismic forces or water pressures to provide a preliminary indication of stability.

TABLE C-1: STABILITY TABLES FOR THREE HINGED BUCKLING

ALPHA=40 DEGREES

RADIUS=10m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	(-20)	(-65)	(-227)	(-482)	(-1788)	(-3873)
15.0	(-23)	(-72)	(-241)	(-503)	(-1832)	(-3956)
20.0	7955	(-77)	(-252)	(-521)	(-1876)	(-4018)
25.0	1105	(-81)	(-261)	(-536)	(-1908)	(-4072)
30.0	545	6297	(-268)	(-548)	(-1935)	(-4114)
35.0	321	2053	266210	(-555)	(-1953)	(-4151)
40.0	227	1106	15887	(-558)	(-1962)	(-4168)
45.0	168	722	5773	48744	(-1961)	(-4175)

ALPHA=40 DEGREES

RADIUS=50m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	(-33)	(-91)	(-281)	(-569)	(-2015)	(-4320)
10.0	13201	(-128)	(-355)	(-681)	(-2247)	(-4678)
15.0	2242	16858	(-417)	(-778)	(-2440)	(-4975)
20.0	1194	4820	47042	(-856)	(-2606)	(-5232)
25.0	849	2782	13688	56754	(-2733)	(-5426)
30.0	667	1945	7500	21112	534700	(-5581)
35.0	543	1500	5040	12169	102900	(-5676)
40.0	431	1157	3651	8096	47206	226160
45.0	348	910	2774	5837	28267	97298

ALPHA=40 DEGREES

RADIUS=100m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	(-53)	(-132)	(-363)	(-694)	(-2302)	(-4764)
15.0	2368	8556	65488	(-1102)	(-3103)	(-5997)
25.0	1260	3394	11073	26028	226420	(-6867)
30.0	1029	2668	7780	16303	84447	362810
35.0	856	2120	5896	11766	48107	144920
40.0	712	1728	4629	8822	32384	83705
45.0	575	1393	3641	6863	23347	55434

ALPHA=40 DEGREES

RADIUS=300m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	25917	(-319)	(-715)	(-1211)	(-3295)	(-6262)
10.0	6199	19811	99187	471910	(-4600)	(-8247)
15.0	4208	11037	34172	77008	589390	(-9917)

TABLE C-1: STABILITY TABLES FOR THREE HINGED BUCKLING CONT'D

ALPHA=55 DEGREES

RADIUS=10m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	(-15)	(-47)	(-165)	(-349)	(-1275)	(-2725)
20.0	5855	(-53)	(-178)	(-370)	(-1321)	(-2806)
30.0	337	4384	(-180)	(-374)	(-1336)	(-2837)

ALPHA=55 DEGREES

RADIUS=30m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	9671	(-90)	(-255)	(-493)	(-1633)	(-3398)
20.0	790	3313	34064	(-576)	(-1816)	(-3688)
30.0	367	1154	4790	14156	389830	(-3721)

ALPHA=55 DEGREES

RADIUS=100m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	3723	38682	(-360)	(-654)	(-1972)	(-3935)
20.0	1031	3160	13236	42131	(-2313)	(-4457)
30.0	547	1471	4614	10120	56612	255720

ALPHA=55 DEGREES

RADIUS=300m

VALUE OF P1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	4326	14094	72214	347960	(-3242)	(-5873)
20.0	2113	5217	14407	28444	119130	379270
30.0	1234	2892	7312	13220	41524	91083

TABLE C-1: STABILITY TABLES FOR THREE HINGED BUCKLING **CONT'D**

ALPHA=70 DEGREES

RADIUS=10m

VALUE OF F1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	(-7)	(-24)	(-87)	(-185)	(-659)	(-1370)
10.0	(-8)	(-26)	(-92)	(-191)	(-672)	(-1385)
15.0	(-8)	(-27)	(-93)	(-195)	(-680)	(-1400)

ALPHA=70 DEGREES

RADIUS=50m

VALUE OF F1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	(-14)	(-38)	(-119)	(-243)	(-853)	(-1797)
10.0	5559	(-47)	(-138)	(-272)	(-912)	(-1895)
15.0	764	6592	(-142)	(-278)	(-926)	(-1925)

ALPHA=70 DEGREES

RADIUS=100m

VALUE OF F1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	(-21)	(-54)	(-152)	(-294)	(-970)	(-2019)
10.0	2035	22235	(-188)	(-349)	(-1085)	(-2186)
15.0	747	3063	26380	(-360)	(-1110)	(-2226)

ALPHA=70 DEGREES

RADIUS=300m

VALUE OF F1 OR (PERTURBING FORCE) (KN)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	10875	(-117)	(-279)	(-486)	(-1367)	(-2638)
10.0	2223	7504	40252	200120	(-1691)	(-3135)
15.0	1212	3386	11464	27519	237260	(-3230)

CORRESPONDING SLAB LENGTHS FOR STABILITY TABLES

Table C-2 shows the value for L1 arising from the analysis for the critical case on Table C-1. As indicated above, for stable situations, L1 was taken as 5T. Other variables are as previously discussed for the stability tables.

TABLE C-2: CORRESPONDING SLAB LENGTHS FOR STABILITY TABLES

ALPHA=40 DEGREES

RADIUS=10m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	2.5	5	10	15	30	45
15.0	2.5	5	10	15	30	45
20.0	30	5	10	15	30	45
25.0	10	5	10	15	30	45
30.0	10	30	10	15	30	45
35.0	5	15	170	15	30	45
40.0	5	10	40	15	30	45
45.0	5	10	25	70	30	45

ALPHA=40 DEGREES

RADIUS=50m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	2.5	5	10	15	30	45
10.0	40	5	10	15	30	45
15.0	20	50	10	15	30	45
20.0	10	20	70	15	30	45
25.0	10	15	40	80	30	45
30.0	10	15	30	50	230	45
35.0	10	10	20	40	100	45
40.0	7	10	20	30	70	150
45.0	5	10	15	25	50	100

ALPHA=40 DEGREES

RADIUS=100m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	2.5	5	10	15	30	45
15.0	20	30	80	15	30	45
25.0	10	20	35	50	150	45
30.0	[illegible]	20	30	40	100	200
35.0	10	15	25	30	70	120
40.0	10	15	20	30	60	100
45.0	7	10	20	30	50	70

ALPHA=40 DEGREES

RADIUS=300m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	60	5	10	15	30	45
10.0	30	40	100	220	30	45
15.0	20	30	60	90	240	45

TABLE C-2: CORRESPONDING SLAB LENGTHS FOR STABILITY TABLES CONT'D

ALPHA=55 DEGREES

RADIUS=10m

VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	2.5	5	10	15	30	45
20.0	30	5	10	15	30	45
30.0	7	25	10	15	30	45

ALPHA=55 DEGREES

RADIUS=50m

VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	35	5	10	15	30	45
20.0	10	22	70	15	30	45
30.0	7	12	25	45	230	45

ALPHA=55 DEGREES

RADIUS=100m

VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	22	70	10	15	30	45
20.0	12	20	42	75	30	45
30.0	8	15	25	37	85	185

ALPHA=55 DEGREES

RADIUS=300m

VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
10.0	24	45	100	220	30	45
20.0	14	25	45	60	125	220
30.0	13	20	30	43	75	110

TABLE C-2: CORRESPONDING SLAB LENGTHS FOR STABILITY TABLES CONT'D

ALPHA=70 DEGREES

RADIUS=10m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	2.5	5	10	15	30	45
10.0	2.5	5	10	15	30	45
15.0	2.5	5	10	15	30	45

ALPHA=70 DEGREES

RADIUS=50m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	2.5	5	10	15	30	45
10.0	35	5	10	15	30	45
15.0	13	38	10	15	30	45

ALPHA=70 DEGREES

RADIUS=100m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	2.5	5	10	15	30	45
10.0	22	70	10	15	30	45
15.0	12	25	75	15	30	45

ALPHA=70 DEGREES

RADIUS=300m
VALUE OF SLAB LENGTH L1 (m)

THETA2 DEG	T=0.5m	T=1m	T=2m	T=3m	T=6m	T=9m
5.0	50	5	10	15	30	45
10.0	22	40	95	210	30	45
15.0	16	27	50	78	230	45

DRIVING FORCE VS SLOPE ANGLE

Charts to aid in determining driving force per 10 m of slope height are shown on Figures C-1a to C-1c. These are intended to aid in the use of the design tables. Variables are defined as follows:

PHI = ϕ - Angle of shearing resistance along bedding
Alpha = α - Slope angle above roll.
T = Thickness of slab.
P = Driving force/10 m slope height above roll.

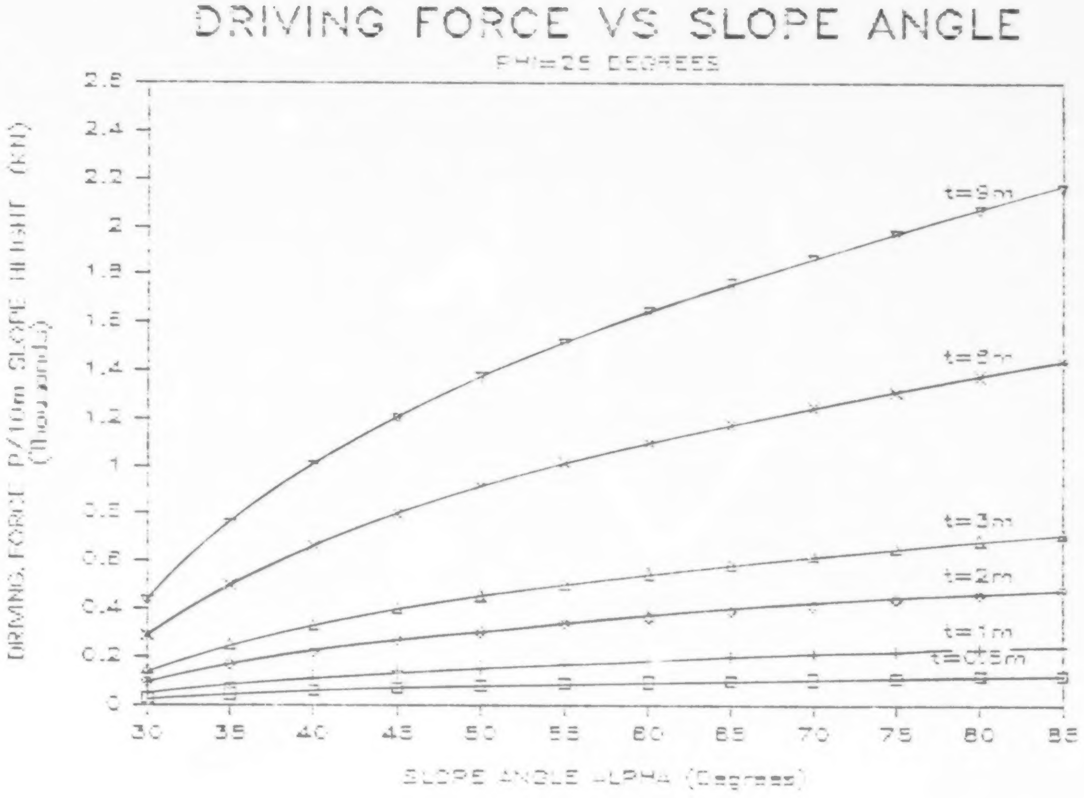


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FIGURE C-1a
PROGRAM "CURVBUK"
STABILITY CHARTS

SCALE AS SHOWN	**DATE** 09/86	**MADE** M G	**CHKD.** D.S.C.	**JOB:** VGO 3957	**PLATE**

HT12 - 79/05

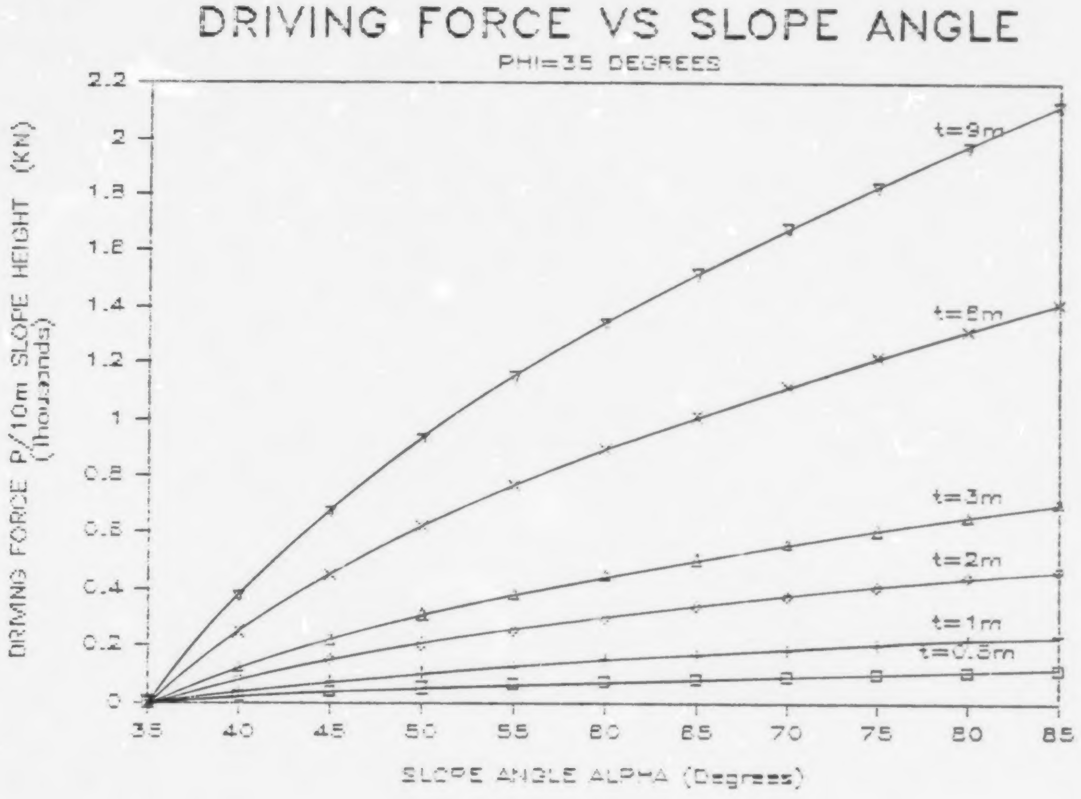

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FIGURE C-1b
PROGRAM "CURVBUK"
STABILITY CHARTS

SCALE AS SHOWN
DATE 09/86
MADE MG
CHKD. DSC
JOB: VG03957
PLATE

HT12 - 79/05

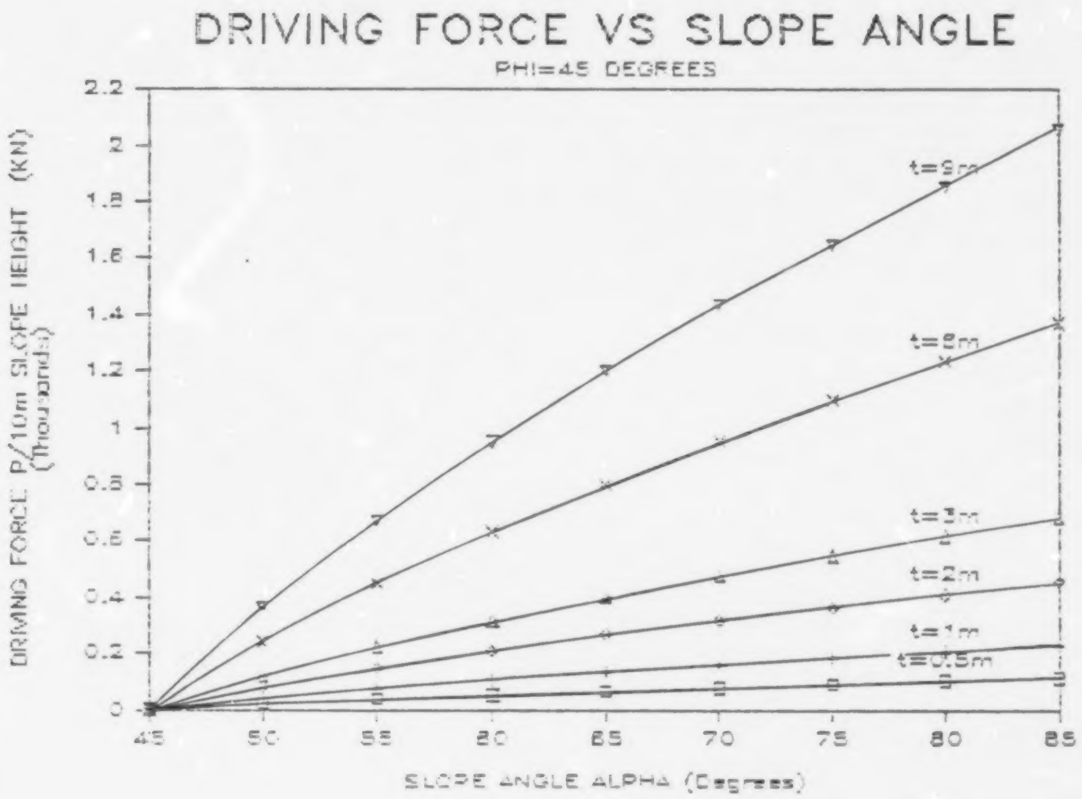

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FIGURE C-1c
PROGRAM "CURVBUK"
STABILITY CHARTS

SCALE AS SHOWN
DATE 09/86
MADE MG
CHKD. DSC
JOB: VG03957
PLATE

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APPENDIX 'D'

BOREHOLE LOGS AND PHOTOGRAPHS - LINE CREEK MINE

VG 03957-A500

EXPLANATION OF TERMS AND GUIDE TO CORED BOREHOLE LOGS

D1.0 GUIDE

The logging procedure involved identification of rock type, engineering descriptions of the rock materials and rock masses, drilling progress, per cent core recovery, depths and reduced levels, in-situ and laboratory test summaries and instrumentation details. Two types of logging procedure were involved:

- simplified logging;
- comprehensive logging.

Simplified logging includes identification of all of the abovementioned parameters with generalized discontinuity descriptions. The simplified logging results are presented on the "Simplified Core Log" sheets. Comprehensive logging is simplified logging plus details of individual discontinuities encountered in the core. The comprehensive logging results are presented on "Simplified Core Log" sheets and "Detailed Discontinuity Log" sheets, both covering the same drilling interval, and appearing consecutively in the core log appendix. Appearing on all core log sheets are details of drilling method, rig type, bit type, drilling period, location, co-ordinates, dip, azimuth and reference elevation (i.e. collar elevation referenced to local datum).

D2.0 SIMPLIFIED CORE LOGS

D2.1 DRILLING AND CASING PROGRESS

This column contains details of drilling dates and the depth at the end of each core run. Where installed, casing details are also given. On this project, depths are given in metres.

D2.2 CORE RECOVERY

Core recovery is defined as the percentage of the total length of core recovered compared to the total drilled length, assessed for each core run (see Figure D1). Occasionally, the apparent core recovery exceeds 100%. This is usually due either to minor errors in depth measurement by the drillers or, more typically, to core stubs being left in the hole, which are subsequently recovered in a consecutive run.

D2.3 ROCK QUALITY DESIGNATION (RQD)

This is an empirical measure defined as the percentage ratio of the total length of rock core fragments of minimum length 100 mm, to the total drilled length (see Figure D1). Rock quality can then be described according to the following table:

RQD (%)	Rock Quality Description
0 - 25	Very poor
25 - 50	Poor
50 - 75	Fair
75 - 90	Good
90 - 100	Excellent

RQD is normally assessed for each core run, and, occasionally, may exceed 100% for similar reasons to those given above, for core recovery. It should be noted that RQD can be affected by drilling equipment and technique, and it is usual practice to include only natural fractures, excluding those induced by drilling.

D2.4 DEPTH

This is the simple measurement of hole depth measured along the borehole axis. On this project, it is measured in metres.

D2.5 REDUCED LEVEL

This is the hole elevation with reference to a specific standard reference system, usually Geodetic Datum (GD).

D2.6 BEDDING/FOLIATION

In this column, the angle between the bedding or foliation relative to the core axis is noted, together with additional bedding and foliation comments. When not noted, no bedding or foliation was visible.

D2.7 FRACTURE INDEX

The fracture index is the ratio of the total number of natural fractures to the total drilled length per core run, and is given in units of number per unit length (in this case, metres). This value usually considers purely natural fractures in rock core. A visual representation of core recovery, solid core recovery (not used on this logging program), RQD, and fracture index is given in Figure D1.

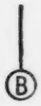
D2.8 TEST RESULTS

In this column, a summary of rock core and borehole test results is presented, where completed. Examples of test results presented are as follows:

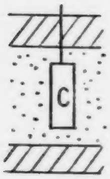
UC 89.2	Unconfined compression test on rock core followed by peak strength value given in MPa;
UC(PLT) 101.4	Point load index test result converted to unconfined compressive peak strength, expressed in MPa;
UC(PLT $\parallel$) 92.6	Point load index test result, parallel to bedding/foliation, converted to unconfined compressive peak strength, expressed in MPa;
UC(PLT $\perp$) 62.8	Point load index test result, perpendicular to bedding/foliation, converted to unconfined compressive peak strength, expressed in MPa;
E 24.5	Young's Modulus, expressed in GPa;
μ 0.28	Poisson's Ratio, dimensionless;
]- K = 4.89	In-situ permeability test result, showing range of borehole tested, expressed in metres per second (x 10^{-9});
T 12.4	Tensile strength, as measured in Brazilian test, expressed in MPa;
γ 2.89	Bulk density, expressed in Mg/m^3.

D2.9 INSTRUMENTATION

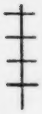
Details of instrumentation installed in the borehole are given in this column. Examples are as follows:



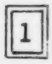
Extensometer anchor location and identifier; extensometers are fully grouted; for data output, refer to entensometer data sheets;



Piezometer location and identifier; all piezometers are set in a gravel blanket, with bentonite seals above and below. The extent of the gravel and seals is shown on the logs. Piezometric level, as recorded on 2nd May, 1986, is given on the riser pipe; for piezometer level fluctuations, refer to piezometric data sheets;



Inclinometer casing installation; casing is fully grouted; for data output, refer to inclinometer data sheets;



Hollow inclusion stress cell location and identifier; for test results, refer to appropriate section of report.

D2.10 DESCRIPTION

In this column, details of colour, grain-size, estimated strength and other natural and/or structural qualities relative to engineering are given, together with a soil or rock name typed in upper case. A brief explanation of some of the descriptive terms used is given in Figure D2. Where joints are present, the descriptive terms shown in Figure D1 have been used, together with details of infilling material, if present.

D3.0 DETAILED DISCONTINUITY LOGS

D3.1 INTRODUCTION

These log sheets are supplementary to the simplified core log sheets, to provide additional, more comprehensive data on discontinuities observed in the rock core, where considered relevant or necessary.

D3.2 DEPTH

In this column, in addition to the hole depth in unit increments, the depth of each observed discontinuity is given below the hole collar, measured along the borehole axis.

D3.3 REDUCED LEVEL

The level of the borehole, reduced to the reference elevation for the hole collar, is given in this column. The levels are given in unit increments, measured vertically.

D3.4 TYPE

In this column, the type of discontinuity is identified and given a name. Discontinuity types identified are as follows:

Fracture (Fract.)	Any discontinuity in rock which cannot readily be identified as one of the terms below;
Joint (Jnt)	A discontinuity which occurs on a pre-existing plane of weakness (e.g. bedding, foliation, schistosity);
Fault (Flt)	A discontinuity along which there has been an observable amount of displacement.

Defined drilling breaks (DB's) are ignored in the logging process; however, possible drilling breaks are included, with appropriate notes in the "Comments" column.

D3.5 ORIENTATION

The orientation of the discontinuity in space is defined using two terms, dip and dip direction ($\propto$). The discontinuity dip is measured between the discontinuity plane and the core axis, and can be measured using a core goniometer or a sensitive protractor. The discontinuity dip direction ($\propto$) is the angle around the core from a reference line to the lowest intersection point of the discontinuity plane with the core. All measurements are made clockwise around the core when looking in a downhole direction, using a linear protractor.

The location of the reference line, scribed on the core, is of great importance and should be clearly defined. In dipping sedimentary rocks, this is easily achieved by locating the reference line along the bedding dip direction on the core surface (i.e. the reference line joins all the lowest intersection points of bedding planes with the core). In horizontally-bedded rocks and those with no bedding (e.g. plutonic rocks), the reference line location is often more difficult to define specifically. Typical conventions used are to locate the reference line on the top of the core (for inclined holes) or on the north side of the core. On this project, in sedimentary rock, the reference line is along the bedding dip direction, as shown in Figure D3.

In highly fractured core, it is sometimes impossible to orient the core, in which case the dip direction ($\propto$) is unknown.

Discontinuity dip and dip direction values relative to core axis and reference line given on the log sheets have to be corrected for borehole orientation to determine the true dip and dip direction relative to the horizontal and grid north.

D3.6 ROUGHNESS

The roughness of the discontinuity surface is presented in two forms - a relative description of the roughness (desc.) and a measurement of the roughness due to small scale asperities in degrees (i), using a needle profilometer.

The roughness description includes both overall form and surface texture. Terms used are as follows:

Overall Form	Surface Texture	Adjectives
P - Planar	P - Polished	V - Very
C - Curved	SL - Slickensided	M - Moderately
ST - Stepped	S - Smooth	
IR - Irregular	R - Rough	

Examples of these terms are given in Figure D1.

The roughness angle (i) is measured in degrees as the maximum deviation caused by an asperity from a straight line joining the two ends of the discontinuity profile traced from a needle profilometer.

D3.7 SURFACE COATING

In this column, details of any surface mineralization, residual alteration and/or conformable depositional materials observed on the discontinuity are noted.

D3.8 INFILL MATERIAL

In this column, details of any non-conformable depositional materials (e.g. clay gouge) and intruded mineralization are presented.

D3.9 GOUGE WIDTH

The width of any gouge, measured perpendicular to the discontinuity, is noted in this column.

D3.10 WEATHERING

The extent of discontinuity weathering is presented, using the following terminology:

F - Fresh: no visible signs of weathering;

FW - Faintly weathered: weathering limited to the surface of major discontinuities;

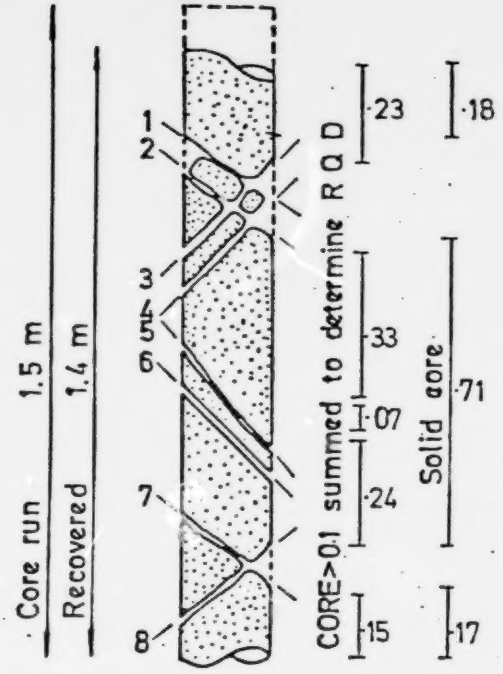
SW - Slightly weathered: penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material;

MW - Moderately weathered: weathering extends throughout the rock mass but the rock material is not friable;

HW - Highly weathered: weathering extends throughout the rock mass and the rock material is partly friable;

EW - Extremely weathered: rock is wholly decomposed and in a friable condition but the rock texture and structure are preserved;

RS - Residual soil: a soil material with the original texture, structure and mineralogy of the rock completely destroyed.

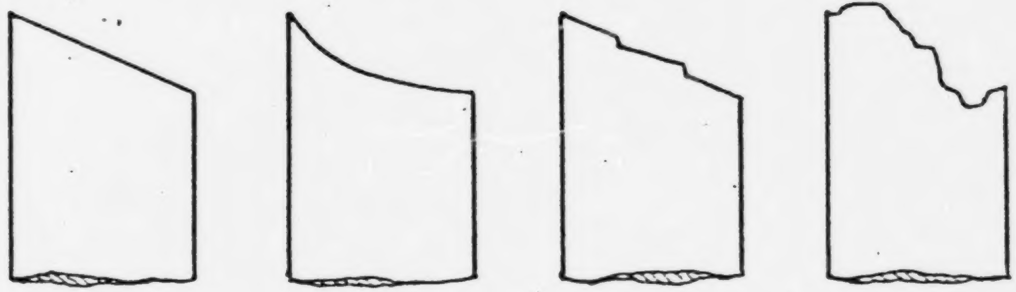

Core run 1.5 m
Recovered 1.4 m
1
2
3
4
5
6
7
8
CORE>0.1 summed to determine RQD
·23
·33
·07
·24
·15
Solid core
·18
·71
·17

Core recovery $= \frac{1.40}{1.50} = 93\%$

Solid core recovery $= \frac{1.06}{1.50} = 71\%$

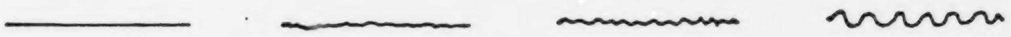
RQD $= \frac{0.95}{1.50} = 63\%$

Fracture index $= \frac{8}{1.50} = 5.3$ /m run



Planar (P) Curved (C) Stepped (ST) Irregular (IR)

OVERALL FORM



Polished (P) Slickensided (SL) Smooth (S) Rough (R) V. Rough (VR)

SURFACE TEXTURE

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FIGURE D1
ROCK MASS DESCRIPTION

SCALE N/A | DATE 04-07-86 | MADE GJK | CHKD. GJB | JOB: VG03957 | PLATE

HT12 - 79/05

The tables given below and overleaf are taken from the format proposed for mining and civil engineering purposes by the Geological Society of London Engineering Group in their Quarterly Journal of Engineering Geology Vol. 10 no. 4 1977 to which reference should be made for the full details of the recommended method.

Descriptive indices for rock material are: **Colour, grain size, weathering and alteration, rock type and strength.**

Rock colour

1	2	3
Light	Pinkish	Pink
Dark	Reddish	Red
	Yellowish	Yellow
	Brownish	Brown
	Olive	Olive
	Greenish	Green
	Bluish	Blue
		White
	Greyish	Grey
		Black

Grain size

Term	Particle size	Retained on BS Sieve No. (approx)	Equivalent Soil Grade
Very coarse-grained	>60 mm	2 in	Boulders + Cobbles
Coarse-grained	2–60 mm	8	Gravel
Medium-grained	60 microns-2 mm	200	Sand
Fine-grained	2–60 microns		Silt
Very fine-grained	<2 microns		Clay

Note: grains >60 microns diameter are visible to the naked eye

Weathering/alteration grades

Term	Description	Grade
Fresh	No visible sign of rock material weathering	IA
Faintly weathered	Discoloration on major discontinuity surfaces.	IB
Slightly weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the material may be discoloured by weathering and may be somewhat weaker than in its fresh condition	II
Moderately weathered	Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or corestones.	III
Highly weathered	More than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or corestones	IV
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported	VI

Rock material strength

Term	Unconfined Compressive Strength MN/m^2 (MPa)	Field estimation of hardness
Very strong	>100	Very hard rock–more than one blow of geological hammer required to break specimen
Strong	50–100	Hard rock–hand held specimen can be broken with a single blow of geological hammer
Moderately strong	12·5–50	Soft rock–5 mm indentations with sharp end of pick.
Moderately weak	5·0–12·5	Too hard to cut by hand into a triaxial specimen.
Weak	1·25–5·0	Very soft rock– material crumbles under firm blows with the sharp end of a geological pick.
Very weak rock or hard soil	0·60–1·25	Brittle or tough, may be broken in the hand with difficulty.
Very stiff	0·30–0·60*	Soil can be indented by the fingernail
Stiff	0·15–0·30	Soil cannot be moulded in fingers
Firm	0·08–0·15	Soil can be moulded only by strong pressure of fingers
Soft	0·04–0·08	Soil easily moulded with fingers
Very soft	0·04	Soil exudes between fingers when squeezed in hand

* The compressive strengths for soils given above are double the unconfined shear strengths.

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FIGURE D2
ROCK MATERIAL DESCRIPTION

SCALE N/A
DATE 01-07-86
MADE GJB
CHKD. GJB
JOB: VG03957
PLATE

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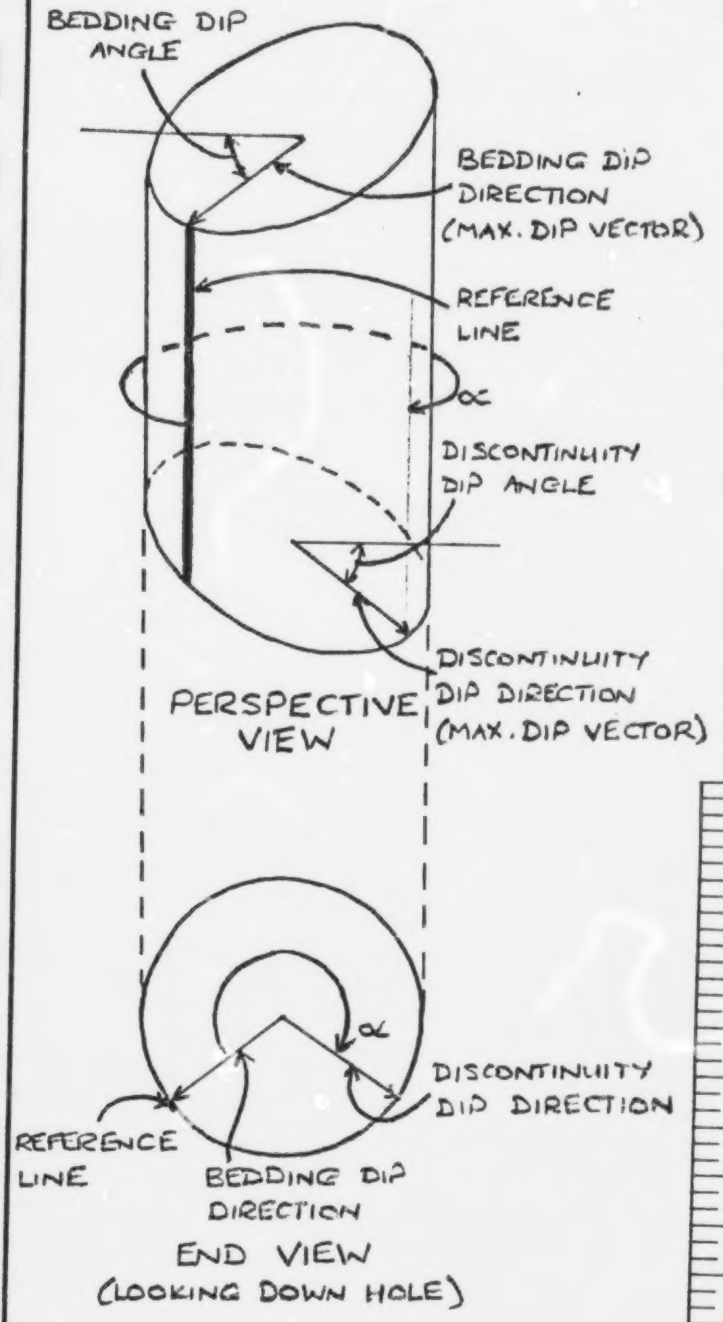
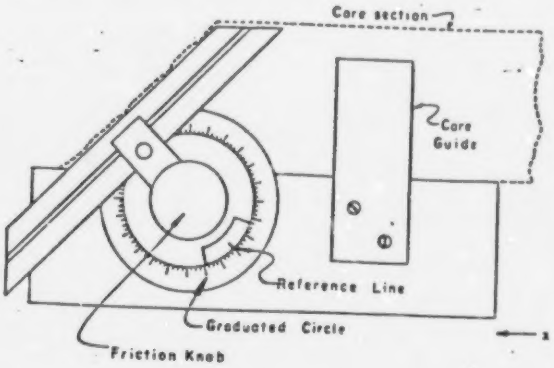
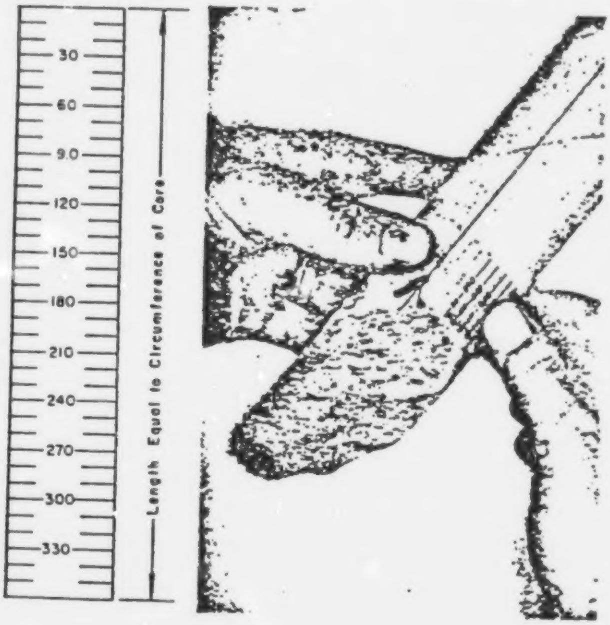

BEDDING DIP ANGLE
BEDDING DIP DIRECTION (MAX. DIP VECTOR)
REFERENCE LINE
α
DISCONTINUITY DIP ANGLE
DISCONTINUITY DIP DIRECTION (MAX. DIP VECTOR)
PERSPECTIVE VIEW
α
DISCONTINUITY DIP DIRECTION
REFERENCE LINE
BEDDING DIP DIRECTION
END VIEW
(LOOKING DOWN HOLE)


Core section
Core Guide
Reference Line
Graduated Circle
Friction Knob
x

CORE GONIOMETER


30
60
90
120
150
180
210
240
270
300
330
Length Equal to Circumference of Core

LINEAR PROTRACTOR

NOTE: BOTH BEDDING AND DISCONTINUITY DIP ARE MEASURED RELATIVE TO THE CORE AXIS AND MUST BE CORRECTED USING HOLE SURVEY RESULTS.

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FIGURE D3
DETERMINATION OF DIP AND DIP DIRECTION OF DISCONTINUITIES IN SEDIMENTARY ROCK CORE

SCALE N/A
DATE 07/07/86
MADE GJB
CHKD. GJB
JOB: VG03957
PLATE

HT12 - 79/05

D4.0 CORE PHOTOGRAPHS

All rock core was photographed in colour at our laboratories in Burnaby. These photographs follow the appropriate hole log sheets.

SIMPLIFIED CORE LOG

Type of Drilling Rotary, Water-Flush, Wire-Line	**Logged by** F.H. Shrimer	**Drillhole No.** 86 - E1	
Rig Drilcor Assembled	**Checked by** G.J. Baldwin	**Sheet** 1 **of** 2	
Bit NQ, Diamond	**Location** Line Creek Mine	**Dip** 45° Below Horizontal	
Date started APRIL 16, 1986	**Co-ordinates** 659555.904E 5533738.132N	**Azimuth** 246° Grid	
Date finished APRIL 16, 1986		**Ref. Elev.** 1799.783 m.G.D.	

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation
16-04-86 1.37	100	85	1	1799	Thin Bedded 75-90	3.9	UC(PLT) 94.1	
2.89	100	95	2	1798		2.6		
4.42	96	96	3 4	1797		1.3		Ⓐ
5.94	98	80	5	1796		5.0	UC(PLT) 103.0	
7.47	98	80	6 7	1795	Cross Bedded 70-110	5.0		Ⓑ
8.99	99	82	8	1794		5.0		
10.52	99	82	9 10	1793		5.0		Ⓒ
12.04	99	83	11	1792		5.6	UC(PLT) 123.2	
13.57	99	83	12 13	1791		5.6	UC(PLT) 59.5	
	99	83	14	1790			UC(PLT) 21.3	

DESCRIPTION

0.0-8.99 m. SANDSTONE, fine-grained, med. grey, strong to very strong - joints generally irregular, rough.

3.4-5.6 m - Occasional conglomeratic zones.

4.4-4.5 m - Brown

5.5 m - Cross Bedded.

8.99-9.5 m COAL, brittle, weak, becoming carbonaceous mudstone.

9.5-13.57 m SANDSTONE, fine grained, med. grey, strong to very strong, cross bedded.

12.0 m coal laminations become common.

13.57-14.3 m COAL, brittle, weak, becoming carbonaceous mudstone.

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Extensometer Hole

HARDY ASSOCIATES (1978) LTD.
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SIMPLIFIED CORE LOG

Type of Drilling Rotary, Water-Flush, Wire-Line	Logged by F.H. Shrimer	Drillhole No. **86-E1**
Rig Drilcor Assembled	Checked by G.J. Baldwin	Sheet 2 of 2
Bit HQ, Diamond	Location Line Creek Mine	Dip 45° Below Horizontal
Date started APRIL 16, 1986	Co-ordinates 659555.904E 5533738.132N	Azimuth 246° Grid
Date finished APRIL 16, 1986		Ref. Elev. 1799.783 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m)	Test Results	Instru-mentation	DESCRIPTION
									COAL (cont'd)
15.09 16-04-86	99	83	15		Thin Bedded	5.6		Ⓓ	14.3-15.09 m SANDSTONE, fine grained, med. grey, strong to very strong - joints high angle limonite filled.

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

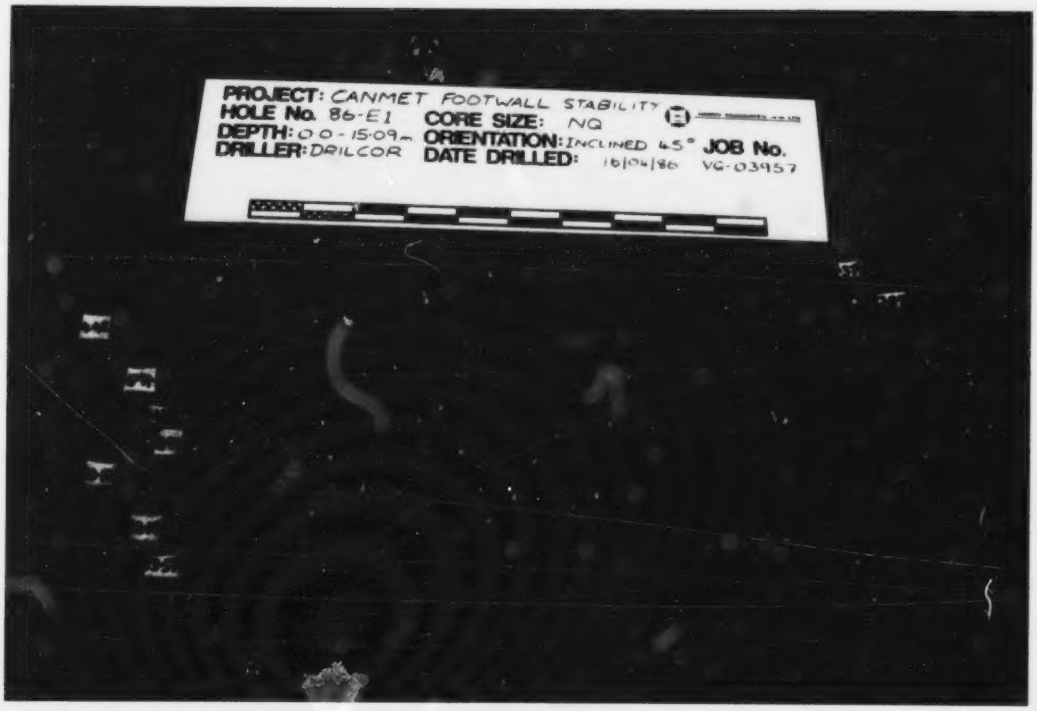
Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Extensometer Hole

HARDY ASSOCIATES (1978) LTD.

CONSULTING ENGINEERING & PROFESSIONAL SERVICES



PROJECT: CANMET FOOTWALL STABILITY
HOLE No. 86-E1 CORE SIZE: NQ
DEPTH: 0.0 - 15.09m ORIENTATION: INCLINED 45°
DRILLER: DRILCOR DATE DRILLED: 16/04/86
JOB No. VG-03957

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 16, 1986	Co-ordinates	659556.627E 5533738.416N
Date finished	APRIL 17, 1986		

Drillhole No. **86-11**

Sheet 1 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.845 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
16-04-86 1.0	102	91	0	1798	Thin Bedded @ 45°	4.0			0.0-12.7 m SANDSTONE - fine to med. grained, strong, light to med. grey, fresh.
2.53	100	80	1.0 2.0	1797		6.5			
4.05	99	86	3.0	1796 1795		3.3	UC(PLT) 103.4		-3.0 m, bedding becomes more distinct.
5.58	96	96	4.0 5.0	1794		0			
	101	97	6.0 7.0	1793 1792		2.0			

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 16, 1986	Co-ordinates	659556.627E 5533738.416N
Date finished	APRIL 17, 1986		

Drillhole No. **86-11**

Sheet 2 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.845 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
0											
0.04		Fract	45	90	IRR	18	Coal	-	-	FR	
0.22		Fract	50	320	IRR	20	-	-	-	FR	
0.41		JNT	45	30	IRMS	16	Coal	-	-	FR	
0.47		JNT	45	20	STMS	28	Coal/None	-	-	FR	
	-1798										
1.0											
1.33		JNT	45	10	PR	10	Limonite	-	-	FR	
1.42		JNT	85	180	STMR	40	Coal,Clay	-	-	SW	Sub-parallel Joint Set
1.44		JNT	89	-	PMS	10	Coal,Clay	-	-	SW	
1.62		JNT	45	190	PMR	6	-	-	-	FR	
1.70		Fract	30	120	IRR	29	-	-	-	FR	
1.75		JNT	45	120	PSL	23	Lim,Clay	-	-	FW	
1.84	-1797	JNT	45	180	IRR	27	-	-	-	FR	
2.0											
2.15		Fract	45	180	IRR	19	Limonite	-	-	FR	
2.70		JNT	45	0	PMS	12	Coal	-	-	FR	
2.78		Fract	90	-	IRR	30	-	-	-	FR	Possible D.B.'s
2.84	-1796	Fract	90	-	IRR	38	-	-	-	FR	
3.0											
3.77	-1795	JNT	45	200	IRR	44	-	-	-	FR	
4.01 4.0		Fract	45,90	180	STMR	35	-	-	-	FR	
4.18		D.B.	90	-	IRR	12	-	-	-	FR	
	-1794										
5.0											
	-1793										
6.0											
6.34		JNT	45	0	STMR	20	Quartz?	-	-	FR	
6.40		JNT	45	0	STMS	30	Coal	-	-	FR	
6.57		JNT	45	0	PMS	26	Coal	-	-	FR	
	-1792										
7.0											

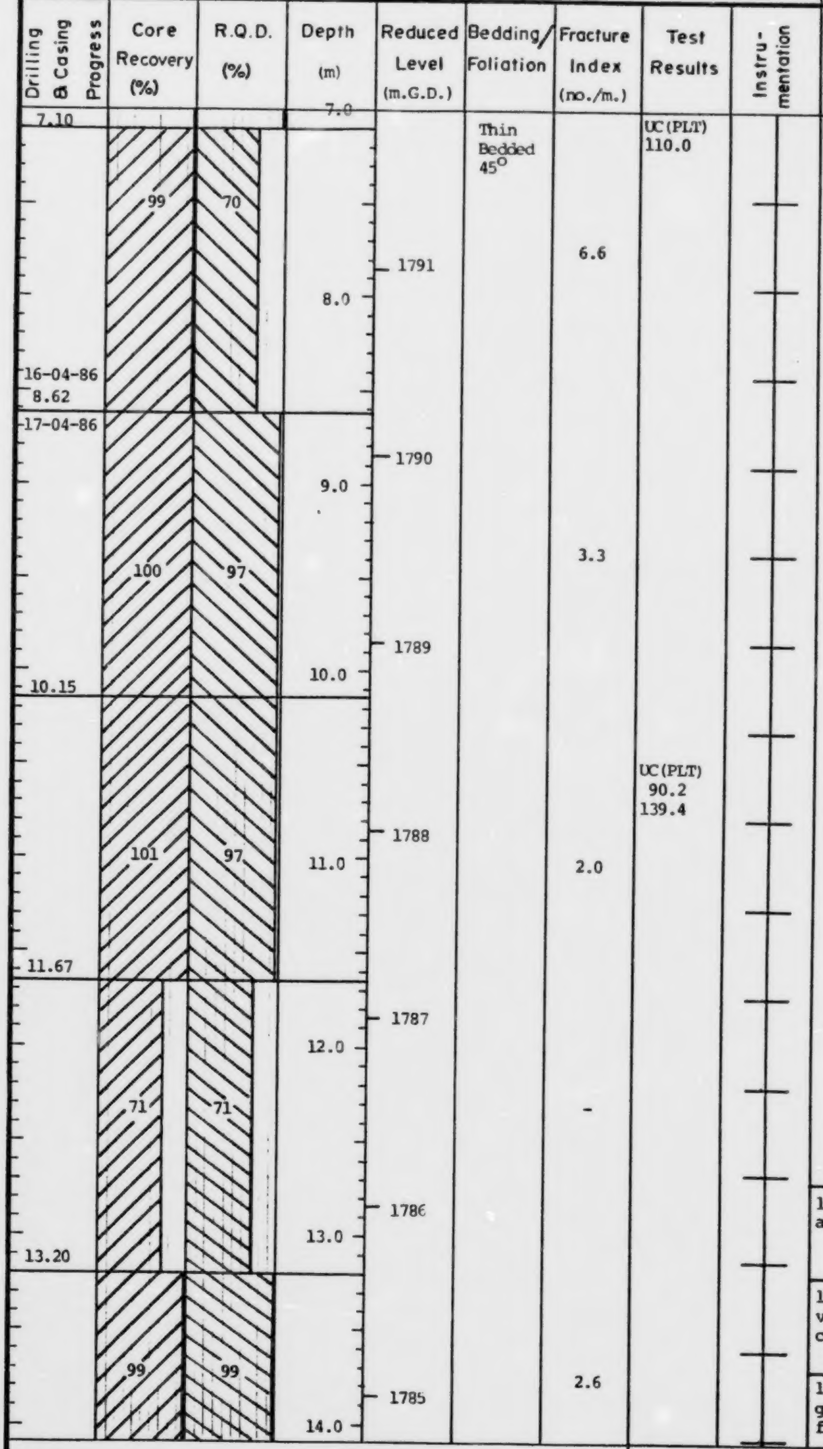
Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-11
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	3 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 16, 1986	Co-ordinates	659556.627E 5533738.416N	Azimuth	-
Date finished	APRIL 17, 1986			Ref. Elev.	1798.845 m.G.D.



Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instrumentation
7.10	99	70	7.0		Thin Bedded 45°	6.6	UC(PLT) 110.0	
			8.0	1791				
16-04-86 8.62 17-04-86	100	97	9.0	1790		3.3		
10.15	101	97	10.0 11.0	1789 1788		2.0	UC(PLT) 90.2 139.4	
11.67	71	71	12.0 13.0	1787 1786		-		
13.20	99	99	14.0	1785		2.6		

DESCRIPTION

7.00-7.10 m, 7.25-7.35 m - Conglomeratic zones.

8.55-8.65 m - Whitish, calcite cemented zone.

12.70-13.20 m - Lost core - assumed to be COAL

13.20-13.70 m MUDSTONE - brownish very dark grey, moderately weak, carbonaceous.

13.70-19.80 m SANDSTONE - fine grained, cross-bedded, strong, fresh, light grey.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.
Remarks	Inclinometer & detailed log hole. For Discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-11
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	4 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 16, 1986	Co-ordinates	659556.627E 5533738.416N	Azimuth	-
Date finished	APRIL 17, 1986			Ref. Elev.	1798.845 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
7.0											
7.10		JNT	45	0	PMR	15	Coal	-	-	FR	
7.21		Fract	40	130	IRR	20	-	-	-	FR	
7.58		JNT	45	10	PMS	15	Coal	-	-	FR	@ 7.40, D.B.
7.65		Fract	90	-	IRR	31	-	-	-	FR	Poss. D.B.
7.80		JNT	45	0	PMS	45	Coal	-	-	FR	
7.88		JNT	45	0	PMS	5	Coal	-	-	FR	
7.97	1791	JNT	45	0	PMS	9	Coal	-	-	FR	
8.0											
8.05		JNT	45	0	PS	23	Coal	-	-	FR	
8.18		Fract	85	175	IRR	23	-	-	-	FR	Poss. D.B.
8.20		JNT	45	0	PR	9	Coal	-	-	FR	
8.28		JNT	45	0	STR	25	Coal?	-	-	FR	8.31 m = D.B.
8.91	1790	JNT	45	0	PMS	18	Coal	-	-	FR	
8.95		JNT	50	0	PS	6	Coal	-	-	FR	
9.0											
9.43		JNT/Fract	45/80	0	PMS/IRR	24	Coal/None	-	-	FR	
9.77	1789	JNT	45	0	CMS	16	Coal	-	-	FR	
10.0											
10.05		JNT	45	0	IRMR	29	Coal?	-	-	FR	
10.50		JNT	45	0	STMR	68	Coal?	-	-	FR	
											D.B. @ 10.62 m
	1788										
11.0											
11.16		JNT	45	0	IRMS	17	Coal	-	-	FR	
11.22		JNT	45	0	IRMS	16	Coal	-	-	FR	
11.67		JNT	45	0	CVS	12	Coal	-	-	FR	
	1787										
12.0											
12.22		JNT	45	0	IRMR	39	Coal	-	-	FR	
12.40		Fract	90/45	330	IRMR	31	Coal/None	-	-	FR	
	1786										
13.0											
13.22		JNT	45	180	IRMS	37	Coal	-	-	FR	
13.28		JNT/Fract	45/90	180	SLS/IRMS	14	Coal/None	-	-	FR	
13.42		JNT	45	0	IRMS	12	Coal	-	-	FR	
	1785										
14.0											

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Drillhole No. **86-11**

Sheet 5 of 8

Type of Drilling: Rotary, Water-Flush, Wire-Line
Rig: Drilcor Assembled
Bit: NQ, Diamond
Date started: APRIL 16, 1986
Date finished: APRIL 17, 1986

Logged by: F.H. Shrimer
Checked by: G.J. Baldwin
Location: Line Creek Mine
Co-ordinates: 659556.627E 5533738.416N

Dip: Vertical
Azimuth: -
Ref. Elev. 1798.845 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
14.72	99	99	14.0		Thin Bedded 45°				13.70-19.80 m SANDSTONE - fine grained, cross-bedded, strong, fresh, light to med. grey.
16.25	100	100	15.0 16.0	1784 1783		2.0			
17.77	100	100	17.0	1782		2.0	UC(PLT) 92.4		
19.30	97	64	18.0 19.0	1781 1780		6.6			
20.82	89	55	20.0	1779		-			19.80-20.70 m MUDSTONE - weak, some severely fragmented portions not recovered, dark brownish grey, carbonaceous.
			21.0	1778					20.70-21.20 m COAL - brittle, weak.

Client: CANMET - COAL RESEARCH LABORATORIES
Project: FOOTWALL STABILITY STUDY
Job No. VG-03957
Drilling Contractor: DRILCOR INDUSTRIES LTD.

Remarks: Inclinometer & detailed log hole. For Discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 16, 1986	Co-ordinates	659556.627E 5533738.416N
Date finished	APRIL 17, 1986		

Drillhole No. **86 - 11**

Sheet 6 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.845 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
14.0											
14.04		JNT	45	0	IRMR	51	Coal	-	-	FR	
	1784										
15.0											
15.78		JNT	45	0	IRS	38	Coal	-	-	FR	
15.91	1783	JNT	40	0	PS	21	Coal	-	-	FR	
16.0											
16.10		Fract	85	0	IRR	-	-	-	-	FR	Poss. D.B.
16.87	1782	JNT	45	10	IRMS	12	Coal?	-	-	FR	
17.0											
17.02		JNT	55	10	IRMS	35	Coal	-	-	FR	
17.37		JNT	45	0	IRMS	25	Coal	-	-	FR	
17.68		Fract	90	-	IRR	18	-	-	-	FR	Poss. D.B.
	1781										
18.0											
18.43		Fract	45	25	IRR	34	-	-	-	FR	
18.52		JNT	45	180	IRSL	37	Coal?	-	-	SW	
18.62		Fract	55	350	IRR	47	-	-	-	FR	
18.70		Fract	90	-	IRR	36	Clay/Lim	-	-	SW	
18.72	1780	JNT	35	0	IRR	21	Clay	-	-	FW	
18.86		Fract	45	70	IRMR	24	-	-	-	FR	
18.98		Fract	70	150	IRR	37	Clay	-	-	FW	
19.0											
19.01		Fract	25	100	CR	27	-	-	-	FR	
19.10		JNT	45	0	IRR	34	Coal	-	-	FR	
19.25		Fract	45	115	PR	23	-	-	-	FR	
19.45		Fract	55	160	IRR	32	-	-	-	FR	
19.79		Fract	35-50	170	IRR	48	Coal/Lim/ Pyrite	-	-	FR-MW	Possibility a combination of a joint & a fracture.
19.90?	1779	JNT	45	230	STMS	42	-	-	-	FR	
20.0											From 19.95-21.05 m, rock mass is too fractured to orient core & meaningfully detail discontinuity surfaces.
	1778										
21.0											

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.

CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	**Logged by**	F.H. Shrimer
Rig	Drilcor Assembled	**Checked by**	G.J. Baldwin
Bit	NQ, Diamond	**Location**	Line Creek Mine
Date started	APRIL 16, 1986	**Co-ordinates**	659556.627E 5533738.416N
Date finished	APRIL 17, 1986		

Drillhole No. 86 - 11

Sheet 7 **of** 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.845 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
			21.0		Bedding Indistinct				COAL (cont'd)
22.35	93	57	22.0	1777		-	UC(PLT) 101.5		21.20-25.40 m SANDSTONE - fine grained, grey, fresh, strong. 21.90-22.60 m, light brown.
23.87	103	103	23.0	1776	Bedding Distinct 45°	1.3	UC(PLT) 74.8		
25.40	99	92	24.0 25.0	1775 1774		1.3			END OF HOLE @ 25.40 m
17-04-86									

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Drillhole No. 86-11

Sheet 8 **of** 8

Type of Drilling Rotary, Water-Flush, Wire-Line
Rig Drilcor Assembled
Bit NQ, Diamond
Date started APRIL 16, 1986
Date finished APRIL 17, 1986

Logged by F.H. Shrimer
Checked by G.J. Baldwin
Location Line Creek Mine
Co-ordinates 659556.627E
5533738.416N

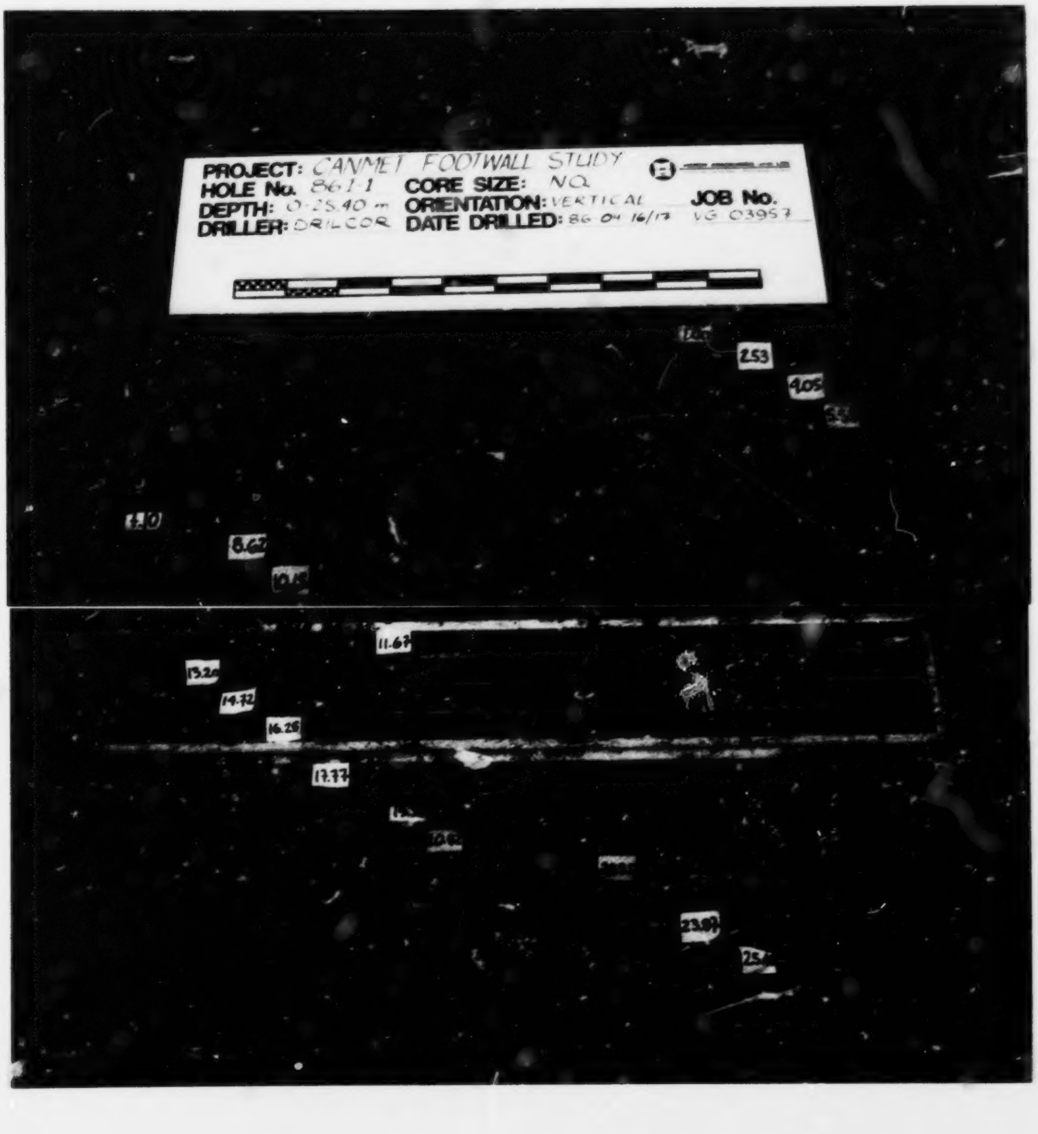
Dip Vertical
Azimuth -
Ref. Elev. 1798.845 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
21.0											
21.12		JNT	30	200	IRR	12	-	-	-	FR	
21.25		JNT	50	320	IRMR	33	Coal	-	-	FR	
21.43		Fract	75	20	STR	38	-	-	-	FR	SFC appears stepped due to fracture pattern of close-spaced parallel joints
21.54		Fract	45-90	180	IRR	50	-	-	-	FR	
21.71		JNT	45	0	PMS	24	Coal	-	-	FR	
21.74	1777	Fract	30	90	IRR	22	Clay?	-	-	FR	
21.95		Fract/DB?	90	-	IRR	-	-	-	-	FR	
22.0											
22.08		Fract	40	180	IRR	31	-	-	-	FR	
22.12		Fract	45	180	IRR	17	-	-	-	FR	22.15 - 22.35 m core is fragmented.
	1776										
23.0											
23.12		JNT	45	0	IRR	17	-	-	-	FR	
23.25		Fract	85	70	IRR	22	-	-	-	FR	Poss. DB
	1775										
24.0											
24.66		Fract	35	200	IRR	35	-	-	-	FR	
	1774										
25.0											
25.26		Fract	40	220	IRR	24	-	-	-	FR	
25.40		END OF HOLE @ 25.40 m									

Client CANMET - COAL RESEARCH LABORATORIES
Project FOOTWALL STABILITY STUDY
Job No. VG-03957
Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES



PROJECT: CANMET FOOTWALL STUDY
HOLE No. 861-1 **CORE SIZE:** NQ
DEPTH: 0-25.40 m **ORIENTATION:** VERTICAL **JOB No.**
DRILLER: DRILCOR **DATE DRILLED:** 86 04 16/17 VG 03957

2.53
4.05
7.10
8.62
11.67
13.20
14.72
16.25
17.77
23.87

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 19, 1986	Co-ordinates	659556.627E 5533738.916N
Date finished	APRIL 19, 1986		

Drillhole No. **86-P1**

Sheet 1 of 2

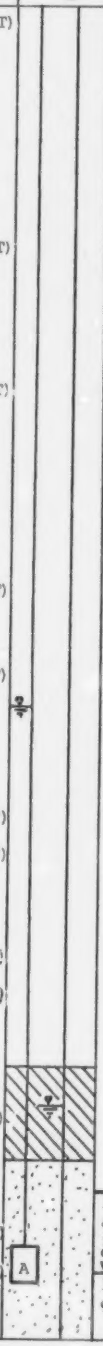
Dip Vertical

Azimuth -

Ref. Elev. 1798.845 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results
19-04-86 0.92	92	74		1798	Thin Bedded 50°	4.3	U.C.(PLT) 87.4
2.44	95	75	1.0 2.0	1797		5.3	
3.97	99	93	3.0	1796 1795		5.3	U.C.(PLT) 89.6
5.49	99	99	4.0 5.0	1794		1.3	U.C.(PLT) 94.1
7.02	100	96	6.0	1793 1792		3.3	U.C.(PLT) 85.1
8.55	98	61	7.0 8.0	1791		8.0	U.C.(PLT) 89.6 K=0
10.07	103	96	9.0	1790 1789		4.0	U.C.(PLT) 58.2 U.C.(PLT) 87.4
11.59	99	95	10.0 11.0	1788		4.0	U.C.(PLT) 87.4 U.C.(PLT) 123.2
13.12	76	69	12.0 13.0	1787 1786		5.3	U.C.(PLT) 107.5 K=4.89
	102	91	14.0	1785		5.3	U.C.(PLT) 28.0 U.C.(PLT) 56.0

Instru-mentation



DESCRIPTION

0.0-12.6 m SANDSTONE, fine to medium grained, light grey, fresh, strong to very strong.

-1.5-1.6 m, fractured zone.

-Joints are stepped-curved, rough, occas. chlorite, coal, limonite.

-2.2-2.3 m, fractured zone.

-2.65 m, high angle joint.

-4.35 m, occasional coarse grained zones.

-5.0 m, occas. bimodal grain sizes.

Thin bedding becomes more distinct.

-6.33 m, fracture on 1cm thick coal seam.

-6.5 m, 3 cm conglomerate band.

-8.10-8.85 m, becomes medium grained.

-8.85 m, coal seam.

-9.00 m, dark grey, fine grained.

-Below 9.0 m, most joints occur on frequent coaly laminations, fracture surfaces are planar to stepped, smooth to moderately rough.

12.60-13.49 m COAL, bituminous-anthracitic grade, brittle, fractured, weak. Grades into carbonaceous MUDSTONE, moderately weak, fractured, dark brown.

13.49-19.50 SANDSTONE, fine-med. grained, grey, fresh, strong.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Piezometer Hole

HARDY ASSOCIATES (1978) LTD.

CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line
Rig	Drilcor Assembled
Bit	NQ, Diamond
Date started	APRIL 19, 1986
Date finished	APRIL 19, 1986
Logged by	F.H. Shrimer
Checked by	G.J. Baldwin
Location	Line Creek Mine
Co-ordinates	659556.627E 5533738.916N
Drillhole No.	86 - P1
Sheet	2 of 2
Dip	Vertical
Azimuth	-
Ref. Elev.	1798.845 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results
14.64	102	91	Thin Bedded 50°	5.3	
16.17	99	98		3.3	UC(PLT) 85.1
17.69	101	100		2.0	UC(PLT) 89.6
19.22	97	78		5.3	UC(PLT) 85.1
20.74	98	33		21.1	K=8.70 UC(PLT ∥) 13.4 UC(PLT ⊥) 39.2
22.27	96	68		9.2	UC(PLT) 56.0
23.79	105	99		2.6	UC(PLT) 94.1
25.32	100	93		3.9	UC(PLT) 94.1
19-04-86					

Depth (m)	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0
Reduced Level (m.G.D.)		1784	1783	1782	1781	1780	1779	1778	1777	1776	1775	1774

Instrumentation: B

DESCRIPTION

SANDSTONE (cont'd)-fine grained, uniform, occas. bimodal zones, fresh, strong, medium grey.

-Fracture surfaces planar to irregular, rough and typically on coal partings.

-Coal laminations more frequent.

-Occas. fractures intersect bedding.

19.50-20.87 m COAL, bituminous(?), brittle, fractured. Pyrite blebs common, (20.45-20.75 m, fractured core) Becomes increasingly argillaceous with depth.

20.87-25.32 m SANDSTONE, massive, occas. coal laminae; light grey, strong, fresh.

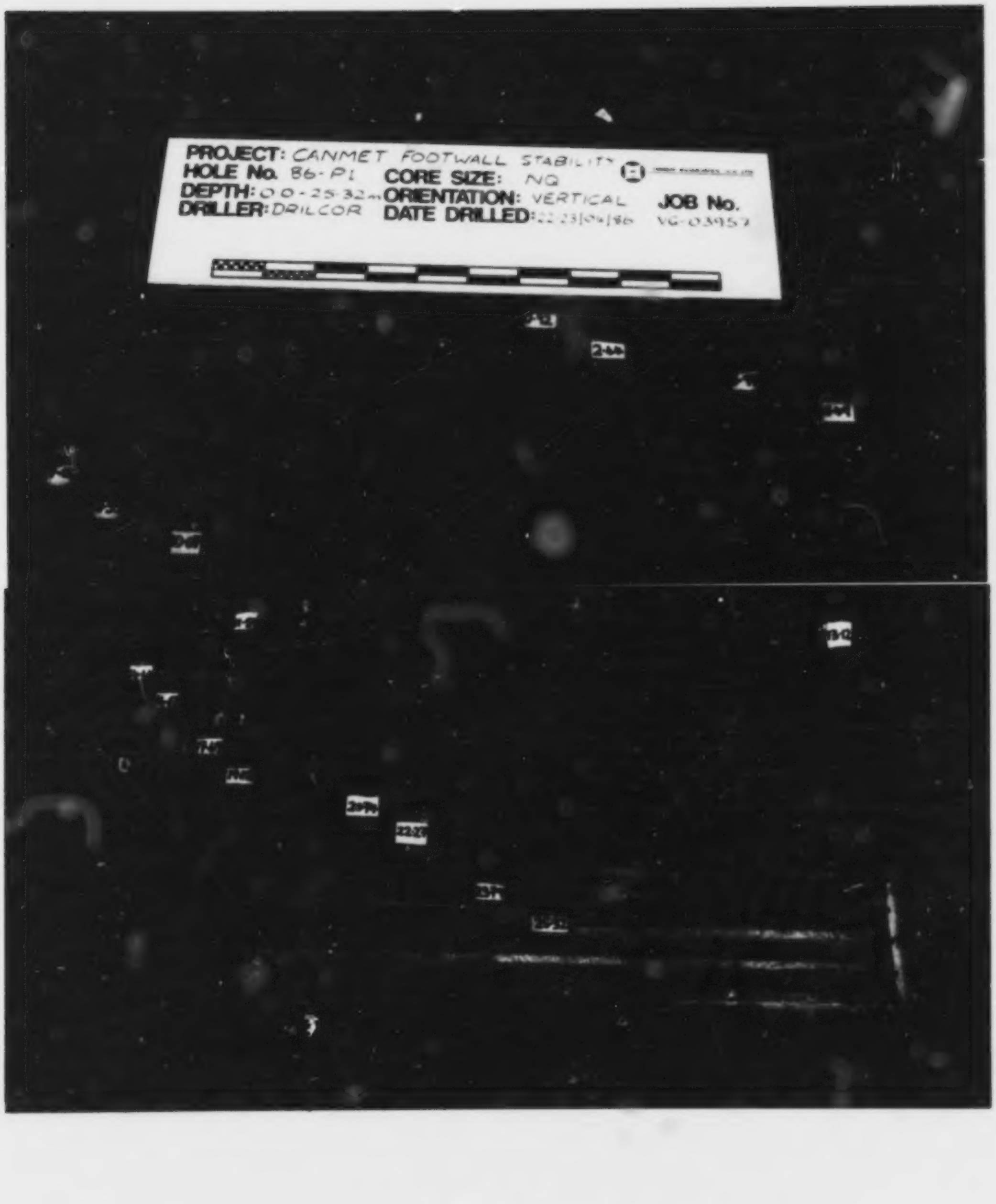
-21.8-22.3 m, light brown

-22.3m, light grey.

END OF HOLE @ 25.32 m

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.
Remarks	Piezometer Hole

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES



PROJECT: CANMET FOOTWALL STABILITY
HOLE No. 86-P1 CORE SIZE: NQ
DEPTH: 0.0-25.32m ORIENTATION: VERTICAL JOB No.
DRILLER: DRILCOR DATE DRILLED: 22-23/04/86 VG-03957

SIMPLIFIED CORE LOG

Type of Drilling: Rotary, Water Flush
Rig: Modified Winkie
Bit: 150 mm diam., Diamond
Date started: APRIL 16, 1986
Date finished: APRIL 21, 1986

Logged by: F.H. Shrimer
Checked by: G.J. Baldwin
Location: Line Creek Mine
Co-ordinates: 659557.176E
5533735.442N

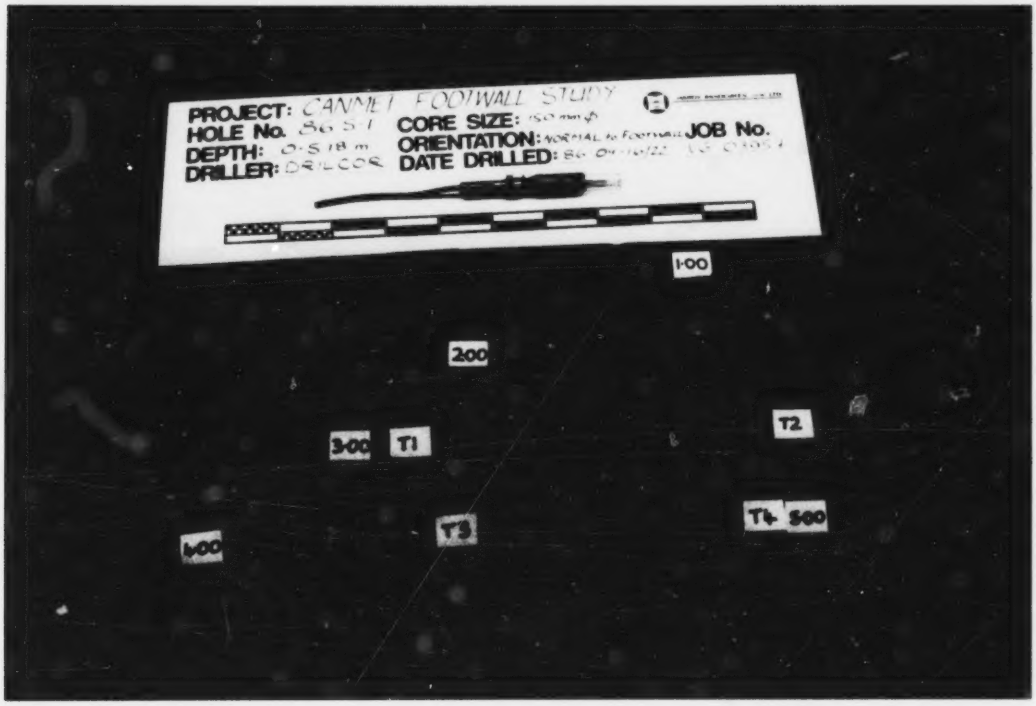
Drillhole No. **86 - S1**
Sheet 1 of 1
Dip: 35° Below Horizontal
Azimuth: 246° Grid
Ref. Elev.: 1799.526 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
16-04-86 0.53	100	92	0		Thin Bedded 65-70°	1.6			0.0-5.04 m SANDSTONE - fine grained, cross-bedded, occas. coaly laminae, medium grey, strong, fresh. -Joints in bedding plane, typically on coal partings. Also high angle joints @ 10° to core axis, limonite-coated, from 0-1.6 m. -2.0-3.0 m occasional conglomeratic zones.
0.86	100	100				0.8			
1.35	100	100	1.0	1799		0.8			
1.96	100	87				2.5			
2.59	103	103	2.0			0.8			
16-04-86 3.22	103	103	3.0	1798		3.3		1	
19-04-86 19-04-86 3.84	102	102				0	UC(PLT) 141.0 144.5 139.0 145.1 131.8	2	
20-04-86 20-04-86 4.46	102	85	4.0	1797		4.9		3	-4.06-4.11 m, brown.
21-04-86 5.18	95	79	5.0			1.6		4	END OF HOLE @ 5.18 m
21-04-86									

Client: CANMET - COAL RESEARCH LABORATORIES
Project: FOOTWALL STABILITY STUDY
Job No.: VG-03957
Drilling Contractor: DRILCOR INDUSTRIES LTD.

Remarks: In Situ Stress Measurement Hole

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES


PROJECT: CANMET FOOTWALL STUDY
HOLE No. 86 S-1
DEPTH: 0-5.18 m
DRILLER: DRILCOR
CORE SIZE: 150 mm ϕ
ORIENTATION: NORMAL to Footwall
DATE DRILLED: 86-04-16/22
JOB No.
1·00
2·00
3·00
T1
T2
T3
T4
5·00
4·00

SIMPLIFIED CORE LOG

Type of Drilling: Rotary, Water-Flush, Wire-Line
Rig: Drilcor Assembled
Bit: NQ, Diamond
Date started: APRIL 24, 1986
Date finished: APRIL 24, 1986

Logged by: F.H. Shrimer
Checked by: G.J. Baldwin
Location: Line Creek Mine
Co-ordinates: 659602.652E
5533632.622N

Drillhole No. **86 - E2**
Sheet 1 of 2
Dip: 45° Below Horizontal
Azimuth: 246° Grid
Ref. Elev.: 1799.521 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
24-04-86 1.20	79	75	0 1.0	1799	Thin Bedded @ Approx. 90°	0.7			0.0-8.82 m SANDSTONE - fine grained, light to med. grey, fresh, strong. -Joint sufaces generally planar, occas. stepped or irregular, rough.
2.72	101	97	2.0	1798		1.3	UC(PLT ∥) 85.1 UC(PLT ⊥) 109.8		
4.25	101	101	3.0 4.0	1797		1.3	UC(PLT) 87.4	Ⓐ	-Coarse grained to conglomeratic zones @ 3.65-4.00 m, @ 4.50m, @ 4.9-5.0 m.
5.77	98	86	5.0	1796		5.3	UC(PLT) 141.1 UC(PLT) 134.4		-@ 5.0-5.4 m becomes laminated fine grained sandstone to coarse grained siltstone. -@ 5.4 m medium grained, cross-bedded.
7.30	100	95	6.0 7.0	1795		2.0		Ⓑ	
8.82	100	80	8.0	1794		5.9	UC(PLT ⊥) 112.0 UC(PLT ∥) 56.0		-High angle joint @ 8.6-8.8 m, filled with 10 mm thick clay gouge.
10.35	99	83	9.0 10.0	1793		9.9	UC(PLT) 116.5	Ⓒ	8.82-9.4 m COAL - brittle, weak grading to carbonaceous mudstone. 9.4-14.05 m SANDSTONE - fine grained, light to medium grey, fresh, strong. -Occas. laminations, carbonaceous mudstone.
11.87	96	96	11.0	1792		1.3	UC(PLT) 85.1		
13.40	97	59	12.0 13.0	1791		9.2			-Near vertical limonite filled joint @ 13.30 m. -@ 13.50 m, slightly weathered, vuggy, coarse grained.
	90	34	14.0	1790			UC(PLT) 15.2		13.6-14.05 m MUDSTONE - dark grey, weak, carbonaceous.

Client: CANMET - COAL RESEARCH LABORATORIES
Project: FOOTWALL STABILITY STUDY
Job No.: VG-03957
Drilling Contractor: DRILCOR INDUSTRIES LTD.

Remarks: Extensometer Hole

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 24, 1986	Co-ordinates	659602.652E 5533632.622N
Date finished	APRIL 24, 1986		

Drillhole No. **86-E2**

Sheet 2 of 2

Dip 45° Below Horizontal

Azimuth 246° Grid

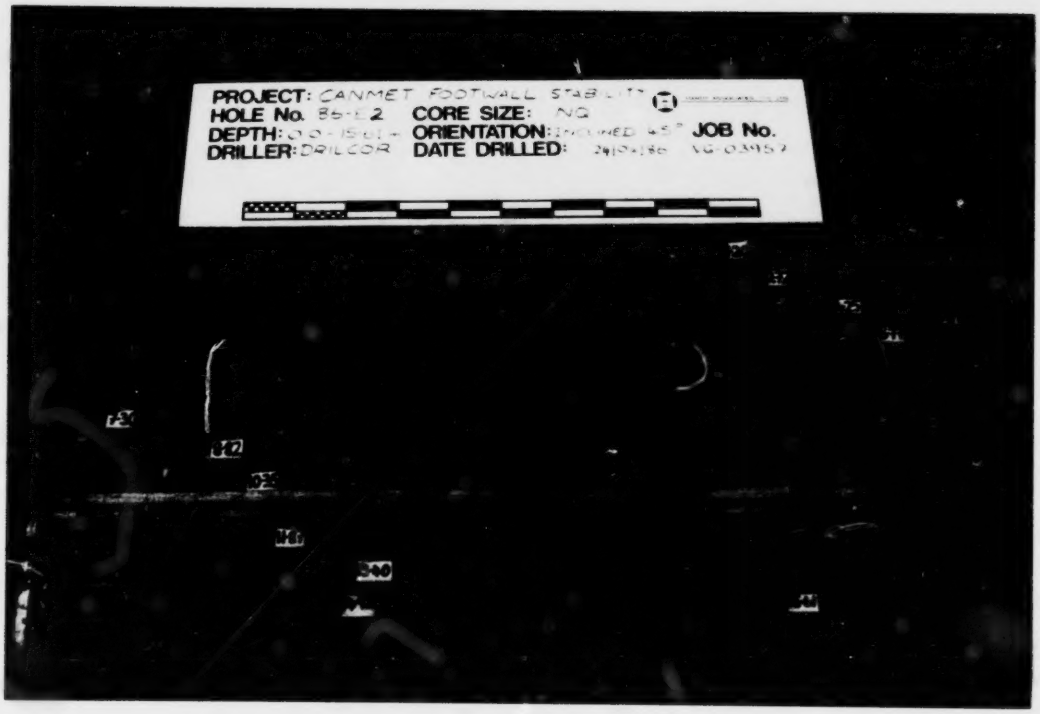
Ref. Elev. 1799.521 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
14.92	90	34	14.0		90°				14.05-14.2 m COAL - brittle, jointed, weak, fragmented.
15.61	100	95	15.0	1789		0.7		D	14.2-15.61 m SANDSTONE - fine grained, light to medium grey, fresh, strong. END OF HOLE @ 15.61 m
24-04-86									

Client	CANMET - COAL RESEARCH LABORATORIES	Remarks	Extensometer Hole
Project	FOOTWALL STABILITY STUDY		
Job No.	VG-03957		
Drilling Contractor	DRILCOR INDUSTRIES LTD.		

HARDY ASSOCIATES (1978) LTD.

CONSULTING ENGINEERING & PROFESSIONAL SERVICES


PROJECT: CANMET FOOTWALL STABILITY
HOLE No. 86-E2
CORE SIZE: NQ
DEPTH: 0.0 - 15.01 +
ORIENTATION: INCLINED 45°
JOB No.
DRILLER: DRILCOR
DATE DRILLED: 24/09/86
VG-03957

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-12
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	1 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 24, 1986	Co-ordinates	659603.201E 5533632.896N	Azimuth	-
Date finished	APRIL 25, 1986			Ref. Elev.	1798.783 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
24-04-86 1.25	93	91	0 1.0	1798	Thin Bedded to laminated @ 45°	1.6			0.0-12.36 m SANDSTONE - fine to med. grained, strong, fresh, med. grey, occas. coal partings.
2.77	103	103	2.0	1797		0.7	UC(PLT) 134.4		2.74-2.90 m, conglomeratic zone.
4.30	98	94	3.0 4.0	1796 1795		2.0			
5.82	100	100	5.0	1794 1793		1.3			4.90-5.10 m - Conglomeratic zone. 5.25-5.70 m - Conglomeratic zone.
	99	84	6.0 7.0	1792		3.3			6.90-7.30 m - Conglomeratic zone.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For discontinuity data see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line
Rig	Drilcor Assembled
Bit	NQ, Diamond
Date started	APRIL 24, 1986
Date finished	APRIL 25, 1986
Logged by	F.H. Shrimer
Checked by	G.J. Baldwin
Location	Line Creek Mine
Co-ordinates	659603.201E 5533632.896N
Drillhole No.	86-12
Sheet	2 of 8
Dip	Vertical
Azimuth	-
Ref. Elev.	1798.783 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation Dip	Orientation ∝	Roughness Descr.	Roughness i	Surface Coating	Infill Material	Gouge Width	Weathering	Comments
0											
0.27		JNT	45	0	IRMS	35	Coal	-	-	SW	
0.29		JNT	45	0	IRMS	35	Coal	-	-	SW	
	1798										
1.0											
1.69		JNT	45	0	PMR	27	Clay	-	-	SW	
	1797										
2.0											
	1796										
3.0											
	1795										
3.88		Fract	45	190	IRR	15	Limonite	-	-	SW	
4.0											
4.02		Fract	50	190	IRR	17	Limonite	-	-	SW	
4.26		JNT	0/60	335	IRR	57	Lim/Coal	-	-	SW	
	1794										
5.0											
5.26		JNT	50	180	IRR	46	Limonite	-	-	FW	
5.60		JNT	45/90	170	IRR	68	Lim/Clay	-	-	FW	
	1793										
6.0											
6.36		JNT	45	5	IRMS	60	Coal	-	-	FR	
6.44		JNT	45	5	IRMS	42	Coal	-	-	FR	
	1792										
6.94		Fract	45	180	IRR	40	-	-	-	FR	Top of conglomerate zone.
7.0											

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole. For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 24, 1986	Co-ordinates	659603.201E 5533632.896N
Date finished	APRIL 25, 1986		

Drillhole No. **86-12**

Sheet 3 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.783 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru- mentation	DESCRIPTION
7.35			7.0				UC (PLT) 120.0		SANDSTONE (cont'd) Conglomeratic zone to 7.30 m. -Occasional coarse grained zones, average 2.5 mm thickness.
8.87	100	100	8.0	1791 1790		2.7			
10.40	99	97	9.0 10.0	1789		3.3			
11.92	100	100	11.0	1788 1787		2.7			
24-04-86 13.45	100	60	12.0 13.0	1786	Massive, but breaks @ 45°	-			12.36-12.85 m COAL - soft, brittle, weak, occas. fresh pyrite blebs. 12.85-13.20 m MUDSTONE - moderately weak. 13.20-19.04 m SANDSTONE - fine to med. grained, strong, fresh, med. grey.
25-04-86	97	95	14.0	1785	Thin bedded @ 45°	2.0			

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For discontinuity data see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-12
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	4 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 24, 1986	Co-ordinates	659603.201E 5533632.896N	Azimuth	–
Date finished	APRIL 25, 1986			Ref. Elev.	1798.783 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
7.0											
7.24		JNT	45	0	PMS	10	Coal	–	–	FR	
7.28		JNT	45	0	PMS	35	Coal	–	–	FR	
7.35		JNT	45	0	PMS	37	Coal	–	–	FR	
7.52		JNT	45	0	IRMR	28	Coal	–	–	FR	
7.64		JNT	45	0	PS	12	Coal	–	–	FR	
	1791										
7.86		JNT	45	15	IRMS	10	Coal	–	–	FR	
8.0											
8.74	1790	Fract	90	–	IRR	62	–	–	–	FR	
9.0											
9.70	1789	JNT	45	0	PMS	33	Coal	–	–	FR	
9.87		JNT	45	0	IRMS	–	Coal	–	–	FR	
9.98		JNT	45	0	PMR	37	–	–	–	FR	
10.0											
10.22		JNT	45	0	PMR	21	–	–	–	FR	
10.36		Fract	80	350	IRR	28	–	–	–	FR	Poss DB?
10.50		JNT	45	10	PR	10	Coal	–	–	FR	
10.67		JNT	45	10	PMR	10	Coal	–	–	FR	
	1788										
11.0											
11.35		JNT	45	10	STR	32	Coal	–	–	FR	
11.75	1787	JNT	45	10	PMR	19	Coal	–	–	FR	
12.0											
12.27		JNT	45	0	IRMS	13	Coal	–	–	FW	Coal Seam (12.36-12.85 m) Fragmented
	1786										
12.83		JNT	45	0	PMS	7	–	–	–	FR	
12.87		JNT	45	0	IRMS	23	–	–	–	FR	
13.0											
13.87	1785	JNT	45	20	PMS	7	Coal	–	–	FR	
13.93		JNT	45	20	PMS	17	Coal	–	–	FR	
14.0											

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.
Remarks	Inclinometer & detailed log hole. For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling: Rotary, Water-Flush, Wire-Line
Rig: Drilcor Assembled
Bit: NQ, Diamond
Date started: APRIL 24, 1986
Date finished: APRIL 25, 1986

Logged by: F.H. Shrimer
Checked by: G.J. Baldwin
Location: Line Creek Mine
Co-ordinates: 659603.201E
5533632.896N

Drillhole No. **86-12**
Sheet 5 of 8
Dip: Vertical
Azimuth: –
Ref. Elev. 1798.783 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
			14.0						SANDSTONE (cont'd)
	97	95				2.0			
				1784					
14.97			15.0						
	101	101				1.3			
				1783					
			16.0						
16.50									
				1782					
			17.0			1.3			
	100	100							
				1781					
18.02			18.0						
	95	69				7.2			
				1780					
			19.0				UC(PLT) 23.3		
									19.04-19.50 m MUDSTONE - mod. weak, carbonaceous.
19.55									19.50-20.05 m COAL - weak, brittle, fractured.
				1779					
			20.0						
	98	66			Indistinct bedding	-			20.05-25.65 m SANDSTONE - fine to med. grained, med. grey, @ 20.30 m becomes light brown.
				1778	Well defined bedding				
			21.0						

Client: CANMET - COAL RESEARCH LABORATORIES
Project: FOOTWALL STABILITY STUDY
Job No. VG-03957
Drilling Contractor: DRILCOR INDUSTRIES LTD.

Remarks: Inclinometer & detailed log hole.
For discontinuity data see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Drillhole No. **86-12**
Sheet 6 of 8

Type of Drilling: Rotary, Water-Flush, Wire-Line
Rig: Drilcor Assembled
Bit: NQ, Diamond
Date started: APRIL 24, 1986
Date finished: APRIL 25, 1986

Logged by: F.H. Shrimer
Checked by: G.J. Baldwin
Location: Line Creek Mine
Co-ordinates: 659603.201E
5533632.896N

Dip: Vertical
Azimuth: -
Ref. Elev.: 1798.783 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
14.0											
14.61		JNT	45	5	CMS	14	Coal	-	-	FR	
	1784										
15.0											
15.43		JNT	80	270	IMR	16	Coal	-	-	FR	
	1783										
16.0											
16.14		JNT	55	350	IRR	34	Coal	-	-	FR	
	1782										
17.0											
17.28		Fract	90	-	IRMR	29	-	-	-	FR	
17.68		JNT	50/90	320	IRMR	37	Coal	-	-	FR	
	1781										
18.0											
18.06		JNT	45	30	IRMS	21	Coal	-	-	FR	
18.48		DB	90	-	IRR	22	-	-	-	FR	
	1780										
18.98		JNT	45	10	IRMS	23	Coal	-	-	FR	Limonite occurs in patches on slickensided fracture surfaces.
19.0											
19.05		JNT	45	20	IRMS	32	Coal	-	-	FR	
19.11		JNT	45	345	SLS	54	Limonite	-	-	FW	
19.20		JNT	70	70	SLS	29	Limonite	-	-	FW	
	1779										
20.0											
20.06		JNT	50	20	IRS	35	Coal	-	-	FW	
20.29		JNT	40	210	PMR	14	Limonite	-	-	FW	
	1778										
21.0											

Client: CANMET - COAL RESEARCH LABORATORIES
Project: FOOTWALL STABILITY STUDY
Job No.: VG-03957
Drilling Contractor: DRILCOR INDUSTRIES LTD.

Remarks: Inclinometer & detailed log hole.
For Simplified log see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 24, 1986	Co-ordinates	659603.201E 5533632.896N
Date finished	APRIL 25, 1986		

Drillhole No. **86-12**

Sheet 7 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.783 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instrumentation	DESCRIPTION
21.07			21.0				UC(PLT) 75.5		SANDSTONE (cont'd) @ 21.0 m becomes arkosic. Clay or gypsum cemented.
	100	97		1777		2.0			
			22.0						
22.60									
				1776					
			23.0						
	103	103				0.7			
				1775					
			24.0						
24.12							UC(PLT) 178.2		
	99	98		1774		1.3			
			25.0						
									-High angle, limonite coated joint @ 25.44 m, and downhole.
25.65									END OF HOLE @ 25.65 m
25-04-86									

Client CANMET - COAL RESEARCH LABORATORIES

Project FOOTWALL STABILITY STUDY

Job No. VG-03957

Drilling Contractor DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole. For discontinuity data see next page.

HARDY ASSOCIATES (1978) LTD.

CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 24, 1986	Co-ordinates	659603.201E 5533632.896N
Date finished	APRIL 25, 1986		

Drillhole No. **86-12**

Sheet 8 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1798.783 m.G.D.

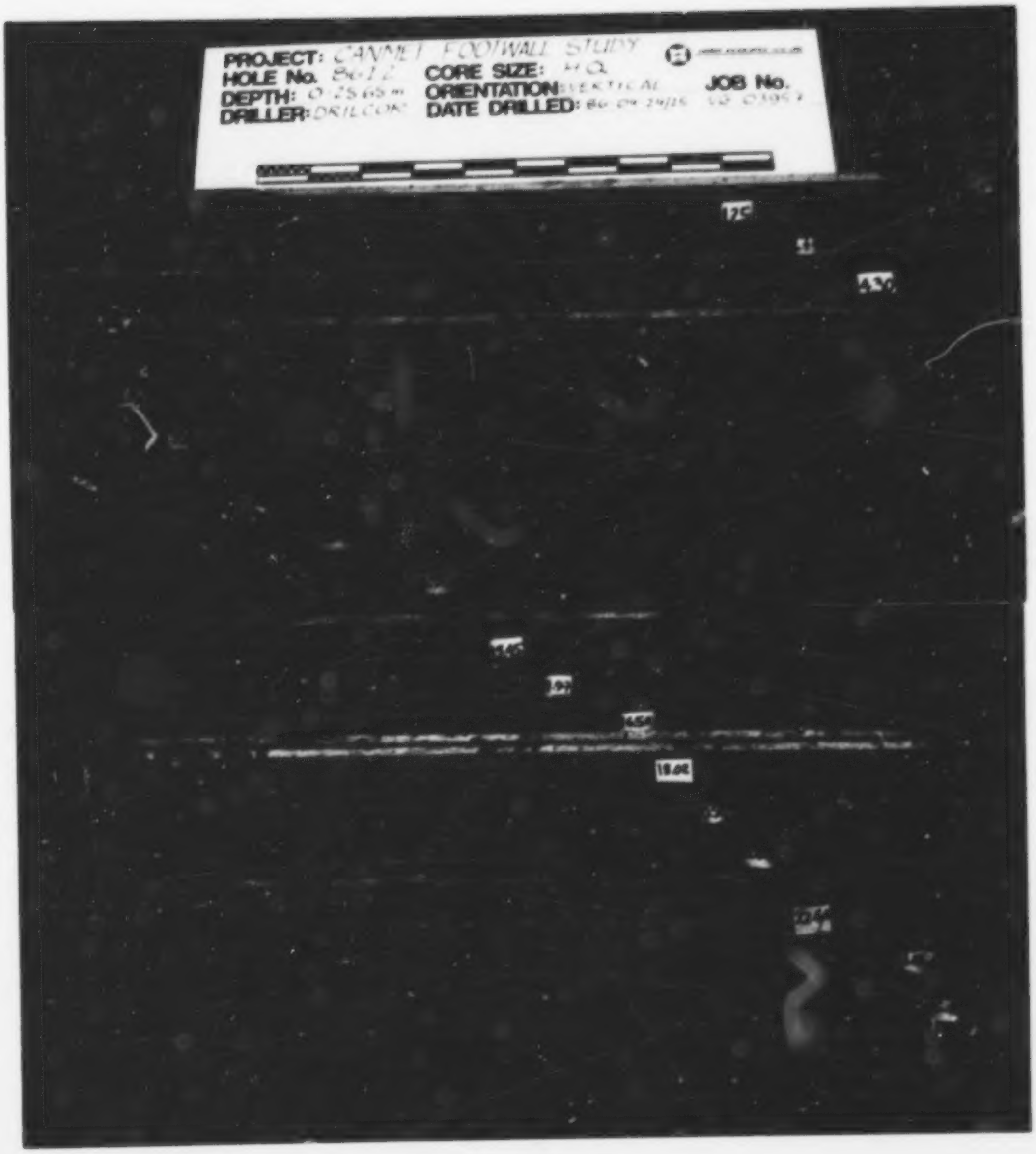
Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
21.0											
21.05		JNT	45	0	[illegible]	23	-	-	-	FR	
21.10		Fract	85	20	IRR	18	Clay	-	-	FR	
21.65	1777	Fract	80	90	CR	14	-	-	-	FR	
22.0											
22.58		JNT	45	0	PR	36	-	-	-	FR	
22.81	1776	JNT	45	345	IRR	50	Coal	-	-	FR	
23.0											
23.23		JNT	30	0	STR	21	-	-	-	FR	
	1775										
24.0											
24.46		DB?	85	160	IRR	29	-	-	-	FR	
	1774										
24.96		Fract	90	-	IRR	21	-	-	-	FR	
25.0											
25.07		JNT	75	270	IRR	40	Limonite	-	-	SW	

END OF HOLE @ 25.65 m

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Inclinometer & detailed log hole.
For Simplified log see previous page.

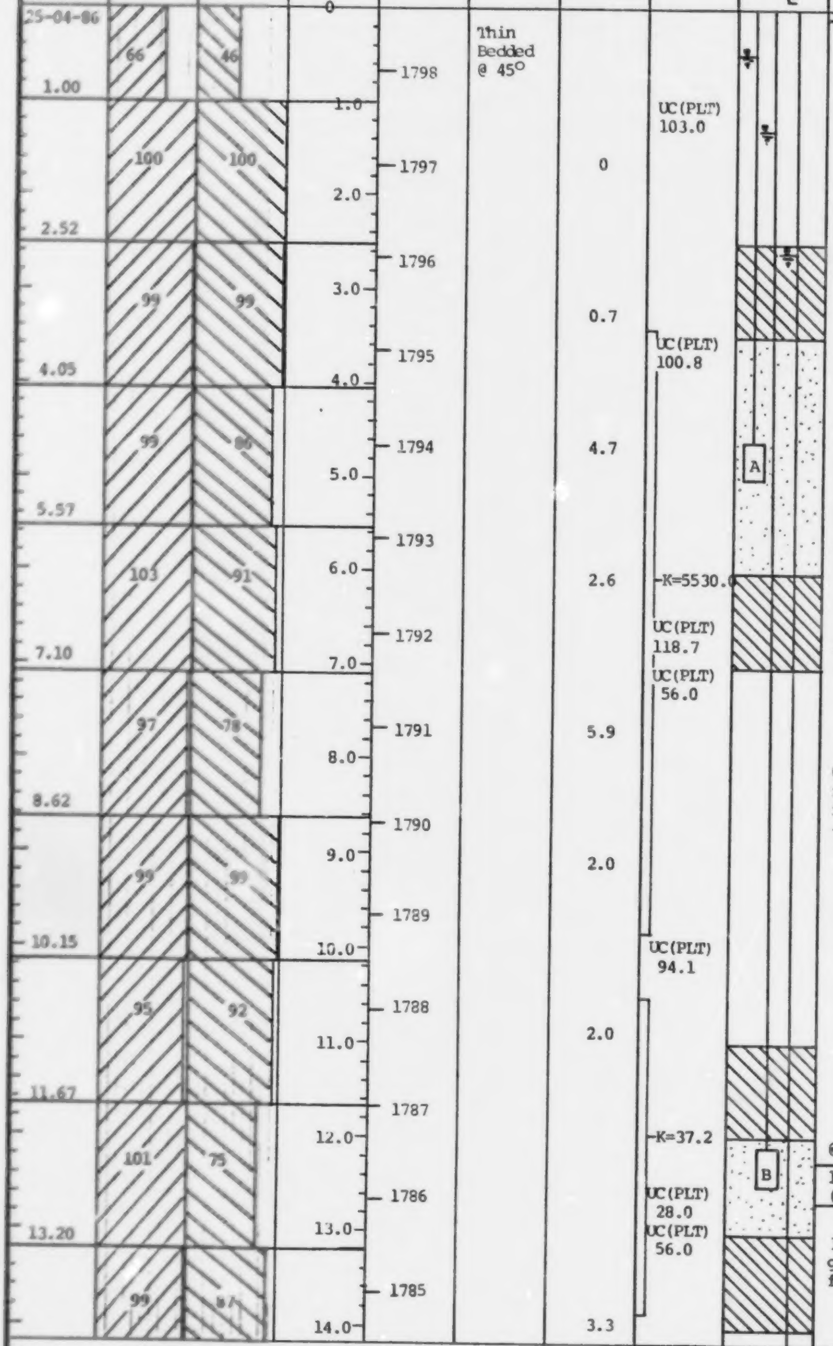
HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES



PROJECT: CANMET FOOTWALL STUDY
HOLE No. 86-12
CORE SIZE: HQ
DEPTH: 0-25.65 m
ORIENTATION: VERTICAL
JOB No. V2 03957
DRILLER: DRILCOR
DATE DRILLED: 86-04-14/15

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-P2
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	1 of 2
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 25, 1986	Co-ordinates	659602.831E 5533633.890N	Azimuth	-
Date finished	APRIL 26, 1986			Ref. Elev.	1798.689 m.G.D.



Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)
25-04-86		
1.00	66	46
2.52	100	100
4.05	99	99
5.57	99	86
7.10	103	91
8.62	97	78
10.15	99	99
11.67	95	92
13.20	101	75
	99	87

Depth (m)	Reduced Level (m.G.D.)
0	
	1798
1.0	
	1797
2.0	
	1796
3.0	
	1795
4.0	
	1794
5.0	
	1793
6.0	
	1792
7.0	
	1791
8.0	
	1790
9.0	
	1789
10.0	
	1788
11.0	
	1787
12.0	
	1786
13.0	
	1785
14.0	

Bedding/Foliation: Thin Bedded @ 45°

Fracture Index (no./m.): 0; 0.7; 4.7; 2.6; 5.9; 2.0; 2.0; 3.3

Test Results:
UC(PLT) 103.0
UC(PLT) 100.8
K=5530.0
UC(PLT) 118.7
UC(PLT) 56.0
UC(PLT) 94.1
K=37.2
UC(PLT) 28.0
UC(PLT) 56.0

DESCRIPTION

0.0-0.1 m COAL - fragmented

0.1-12.25 m SANDSTONE - fine grained, light to med. grey, fresh, strong. Near vertical, limonite filled joints @ 0.15-0.95 m.

-Joint surfaces generally irregular, rough.

-Occas. coaly laminations.
-Cross-bedded.
-Joint set perp. to bedding.

-Occas. coarse grained zones.

-5.20-5.45, conglomeratic zone.
-5.30-5.85, near vertical, limonite filled joint.

-From 5.0-7.5 m, sandstone matrix becomes finer grained, conglomeratic zones are common.

-6.80-7.00 m, high angle joint in conglomerate zone.

@ 8.0 m, becomes thin bedded, finer grained. Increase in frequency of coal laminae.
-Occasional incipient joints perp. to bedding @ 9.2 m.

@ 12.5 m becomes fine grained.

12.25-12.65 m COAL - weak, britt (fragmented), grades to carbonaceous mudstone.

12.75-18.77 m SANDSTONE - fine grained, light to med. grey, fresh, strong.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.
Remarks	Piezometer Hole

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	**86-P2**
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	2 of 2
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 25, 1986	Co-ordinates	659602.831E 5533633.890N	Azimuth	-
Date finished	APRIL 26, 1986			Ref. Elev.	1798.689 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instrumentation
25-04-86 14.72	99	99	14.0	1784	Thin Bedded @ 45°			
26-04-86 16.25	103	101	15.0 16.0	1783		2.6	UC(PLT) 89.6	
17.77	98	85	17.0	1782 1781		3.3		
19.30	96	62	18.0 19.0	1780			K=16.0 UC(PLT) 40.3	C
20.82	100	81	20.0	1779 1778		3.9		
22.35	99	99	21.0 22.0	1777		0.7	UC(PLT) 108.6	
23.87	100	100	23.0	1776 1775		0		
25.40 26-04-86	100	100	24.0 25.0	1774		0	UC(PLT) 89.6	

DESCRIPTION

SANDSTONE (cont'd) - fine grained, light to med. grey, fresh, strong.

-Moderately cross-bedded.
-Joints frequently occur on coaly, irregular surfaces.

-Coal laminae more frequent.

18.77-19.60 m COAL - argillaceous, weak to moderately weak, fragmented, joint surfaces planar, limonite coated, occas. fresh & slickensided. Joint sets commonly intersecting @ random angles.

19.60-25.40 m SANDSTONE - fine grained, grey, fresh, strong.

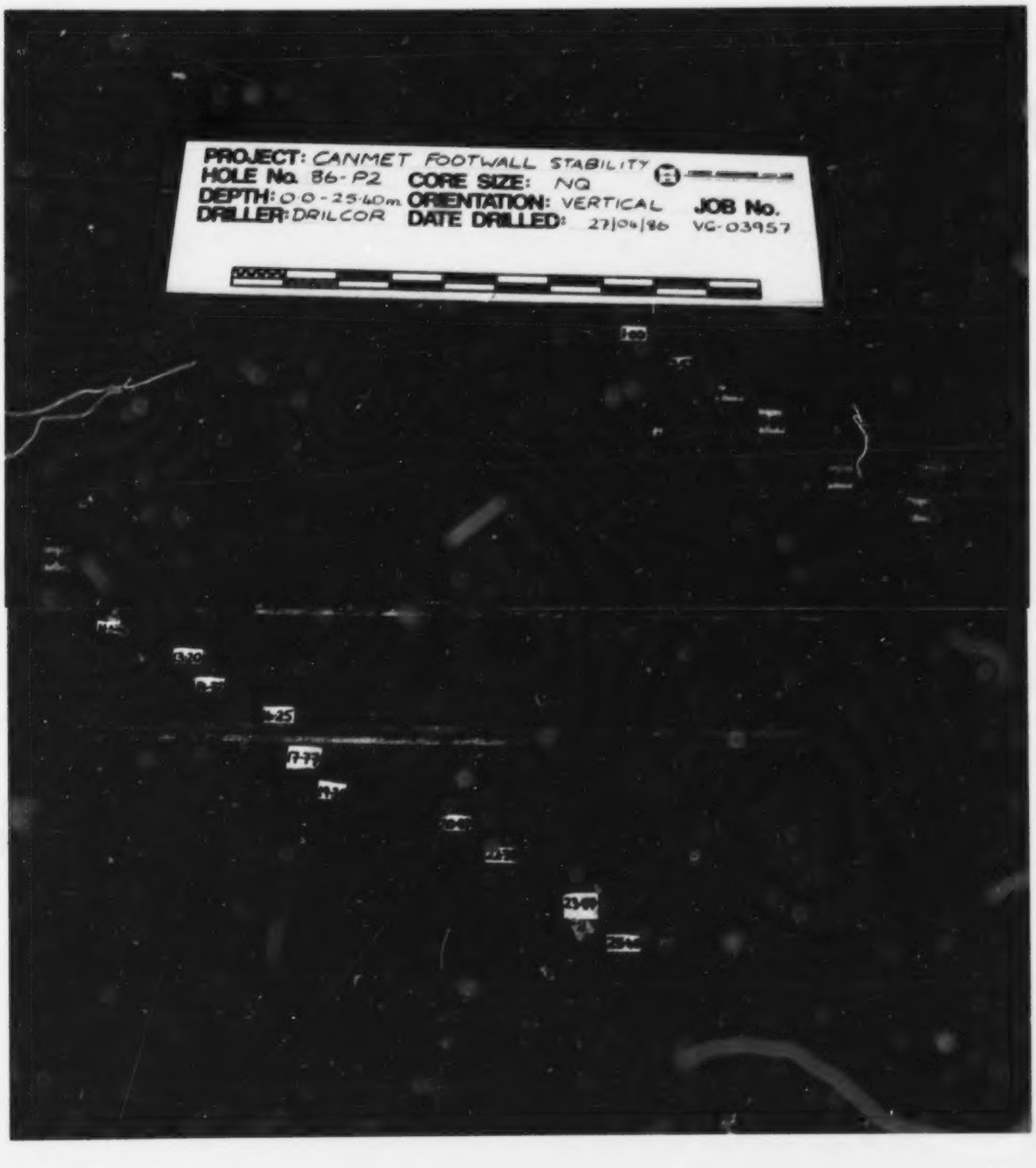
-20.20 m - becomes light brownish, slightly calcareous.

-21.30 m - becomes non-calcareous, cross-bedded.

END OF HOLE @ 25.40 m

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.
Remarks	Piezometer Hole

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES



PROJECT: CANMET FOOTWALL STABILITY
HOLE No. 86-P2 **CORE SIZE:** NQ
DEPTH: 0.0-25.40m **ORIENTATION:** VERTICAL **JOB No.**
DRILLER: DRILCOR **DATE DRILLED:** 27/04/86 VG-03957

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	**86-P3**
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	1 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N	Azimuth	–
Date finished	APRIL 29, 1986			Ref. Elev.	1797.531 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instrumentation	DESCRIPTION
			46.0					20 m Depth	
START OF LOGGING AT 46.62 m DEPTH									
29-04-86					Cross bedded @ 30-50°				46.62-46.72 m COAL 46.72-59.33 m SANDSTONE - fine grained, uniform, light to med. grey, strong.
			47.0						
	99	99				2.6			
				1750			UC(PLT) 87.4		
48.14			48.0						-48.0-48.6 m, Massive texture.
				1749					
	96	84				4.5			
			49.0						
49.67				1748			UC(PLT) 96.3		
			50.0						
	101	95				2.0			
				1747					-Occasional coarse grained zones.
51.19			51.0				UC(PLT) 89.6		
				1746					
	99	99	52.0			2.6	UC(PLT) 94.6		
52.72				1745					
			53.0						-Becoming darker grey; conglomeratic zones more frequent; finer grained matrix.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.
Remarks	Piezometer & detailed log hole. For discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-P3
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	2 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N	Azimuth	-
Date finished	APRIL 29, 1986			Ref. Elev.	1797.531 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
46.0											
46.62	START OF LOGGING AT 46.62 m DEPTH										
46.73		JNT	35	350	IRR	46	Coal	-	-	FR	
46.77		JNT	20	0	PMS	11	Coal	-	-	FR	
46.87		Fract	0-90	290	IRR	46	Coal	-	-	FR	
47.0											
47.14		JNT	50	0	IRR	42	Coal	-	-	FR	
47.18		Fract	50	200	CR	27	-	-	-	FR	
47.78	1750	JNT	50	10	PMS	14	Coal	-	-	FR	
47.82		Fract	70	285	PMR	12	-	-	-	FR	
47.86		JNT	40	180	PR	11	-	-	-	FR	
47.92		JNT	50	350	PMS	6	Coal	-	-	FR	
48.0											
48.02		JNT	40	120	PR	14	-	-	-	FR	
48.10		JNT	40	120	PMR	23	-	-	-	FR	
48.30		JNT	35	130	PR	13	-	-	-	FR	
	1749										
48.90		JNT	45	0	PR	9	-	-	-	FR	
49.0											
49.47		DB	75	90	IRR	-	-	-	-	FR	
49.59	1748	JNT	55	10	PMS	18	Coal	-	-	FR	
50.0											
	1747										
50.80		JNT	0-10	10	CMS	-	Coal, Clay, Pyrite	-	-	FR	
50.90		JNT	50	220	IRR	27	Coal	-	-	FR	
51.0											
51.65	1746	Fract	50	185	IRR	20	-	-	-	FR	
52.0											
52.06		Fract	50	180	PMR	43	Trace Clay	-	-	FW	
52.18		DB	50	180	PMR	-	-	-	-	FR	
52.48	1745	JNT	20	180	PMR	22	Chlorite	-	-	FR	
52.90		JNT	50	180	IRR	14	Clay	-	-	FR	
53.0	53.00	JNT	30	180	PR	9	-	-	-	FR	

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks: Piezometer & detailed log hole. For Simplified log, see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shriner
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N
Date finished	APRIL 29, 1986		

Drillhole No. **86-P3**

Sheet 3 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1797.531 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/Foliation	Fracture Index (no./m.)	Test Results	Instrumentation	DESCRIPTION
54.24	96	84	53.0 54.0	1744	Thin, cross-bedded @ 30-50°	4.5	UC(PLT) 102.5 UC(PLT) 83.6		SANDSTONE (cont'd) - fine grained, med. grey, occas. conglomeratic zones, cross-bedded. 53.45-53.60 m - Conglomeratic zone.
55.77	101	95	55.0	1743 1742		2.0	UC(PLT) 112.2		@ 54.3 m becomes coarser grained, light grey.
57.29	101	97	56.0 57.0	1741		4.6	UC(PLT) 96.8		-Becomes fine grained.
58.82	100	79	58.0	1740 1739		6.6			
	80	53	59.0 60.0	1738		5.9		A	59.33-59.67 m - Lost core - Assumed to be COAL 59.67-60.0 m MUDSTONE - moderately weak, dark brown, carbonaceous.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks: Piezometer & detailed log hole. For discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N
Date finished	APRIL 29, 1986		

Drillhole No. **86-P3**

Sheet 4 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1797.531 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
53.0											
53.29		Fract	30-50	180	IRVR	55	Clay?	-	-	FR	Conglomerate zon
53.34		JNT	45	10	IRMS	55	Coal	-	-	FR	
53.41		Fract	40	200	IRVR	27	-	-	-	FR	
	1744										
53.67		JNT	50	180	STMS	65	Coal	-	-	FR	
53.92		Fract	35	0	IRR	48	-	-	-	FR	
54.0											
54.21		JNT	45	0	PMS	-	Coal	-	-	FR	
	1743										
55.0											
55.12		JNT	40	0	PR	-	Trace Coal	-	-	FR	
55.39		JNT	40	350	PSL	58	Coal	-	-	FR	
55.65	1742	JNT	40	180	STMR	36	Coal	-	-	FR	
55.69		JNT	40	140	CR	22	-	-	-	FR	
55.90		JNT	40	180	PR	12	Coal	-	-	FR	
56.0											
56.40		JNT	40	180	STMR	90	-	-	-	FR	
56.68	1741	Fract	40	165	IRR	16	-	-	-	FR	
56.71		Fract	45	170	IRR	60	-	-	-	FR	
57.02	57.0	JNT	30	120	IRR	40	Clay	-	-	FR	
57.03		JNT	30	120	IRR	-	Clay	-	-	FR	
57.10		JNT	50	10	PR	22	-	-	-	FR	
57.32		JNT	50	0	PMS	34	Coal	-	-	FR	
57.36		JNT	50	0	IRMS	23	Coal	-	-	FR	
57.40	1740	JNT	50	0	PMS	26	Coal	-	-	FR	
57.67		Fract	45	130	STR	30	-	-	-	FR	
57.76		Fract	50	210	STR	81	-	-	-	FR	
57.83		JNT	25	80	STMR	19	Clay	-	-	FR	
57.87		Joint Set	25	80	??	-	??	-	-	??	57.85-57.92,
	58.0	(Incipient)									Incipient Joint Set.
58.24		JNT	45	345	STR	67	Coal	-	-	FR	
58.30		JNT	35	120	IRMR	20	Clay	-	-	FR	
58.46		Fract	50	180	IRR	10	-	-	-	FR	
58.54		JNT	70	0	PR	25	Coal	-	-	FR	
58.59 -	1739	Joint Set	45	180	??	-	??	-	-	??	(Incipient)
58.74		(Incipient)									
58.84		JNT	45	120	SLMS	-	Clay	-	-	FR	Joint Set
58.95	59.0	JNT	45	120	SLMS	90	Clay	-	-	FR	
58.99		JNT	45	120	SLMS	20	Clay	-	-	FR	
59.33		JNT	50	160	IRMR	46	Coal	-	-	FR	Core from 59.33-59.67 is missing.
59.67		JNT	45	160	PS	10	Coal	-	-	FR	
59.75	1738	JNT	35	160	IRMS	71	Coal	-	-	FR	
59.82		JNT	60	90	PMR	25	Coal	-	-	FR	
59.83- 59.86		Joint Set	35	140	IRMR	22	Coal	-	-	FR	
60.0											

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Piezometer & detailed log hole.
For Simplified log, see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N
Date finished	APRIL 29, 1986		

Drillhole No. **86 - P3**

Sheet 5 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1797.531 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
60.34			60.0		Thinly cross-bedded @ 30-50°	5.9			60.0-66.07 m SANDSTONE - fine grained, thinly cross-bedded, grey, strong, fresh.
61.87	98	98	61.0	1737 1736		0			
63.39	99	97	62.0 63.0	1735		2.0			
64.92	99	98	64.0	1734 1733		1.3			
66.44	95	70	65.0 66.0	1732		-			66.07-66.75 m COAL - argillaceous, grades into carbonaceous mudstone, moderately weak.
	100	74	67.0	1731	Thin bedded @ 30-50°	-			66.75-72.52 m SANDSTONE - fine grained, strong, fresh, medium grey.

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VC-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Piezometer & detailed log hole.
For discontinuity data, see next page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer
Rig	Drilcor Assembled	Checked by	G.J. Baldwin
Bit	NQ, Diamond	Location	Line Creek Mine
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N
Date finished	APRIL 29, 1986		

Drillhole No. **86-P3**

Sheet 6 of 8

Dip Vertical

Azimuth -

Ref. Elev. 1797.531 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation Dip	Orientation ∝	Roughness Descr.	Roughness i	Surface Coating	Infill Material	Gouge Width	Weathering	Comments
60.0											
60.13		JNT	45	0	IRMR	26	Coal	-	-	F	
	1737										
61.0											
	1736										
62.0											
	1735										
62.61		Fract	20	30	IRP	30	-	-	-	FR	
62.66		JNT	45	5	VIRMS	41	Coal	-	-	FR	
62.82		JNT	45	5	CMS	23	Coal	-	-	FR	
62.84		JNT	45	5	IRMS	16	Coal	-	-	FR	
63.0											
	1734										
64.0											
64.41		JNT	80?	0	IRR	59	Coal	-	-	FR	
	1733										
64.90		Fract	85	320	IRR	35	-	-	-	FR	Poss. DB
65.0											
65.27		JNT	55	0	IRMR	16	Coal	-	-	FR	
65.54	1732	JNT	45	0	IRMR	12	Coal	-	-	FR	
66.10		JNT	40	0	IRMR	42	Coal	-	-	FR	
66.14		JNT	85	?	IRMS	30	Coal	-	-	FR	
66.15		JNT	75	?	IRS	21	Coal	-	-	FR	
66.17		JNT	55	?	IRS	35	Coal	-	-	FR	
66.20	66.0	JNT	55	?	SLS	26	Coal	-	-	FR	
66.22		JNT	55	?	SLS	24	Coal	-	-	FR	
66.29		JNT	45	?	PMS	30	Coal	-	-	FR	
66.32		JNT	30	?	IRMS	17	Coal	-	-	FR	
66.42		JNT	40	?	IRSLS	40	Coal	-	-	FR	
66.47	1731	JNT	85	?	IRMS	14	Coal	-	-	FR	66.47-66.66 m, fragmented.
66.66		JNT	45	350	PVS	65	Coal	-	-	FR	
66.75		JNT	45	340	IRMS	42	Coal	-	-	FR	
67.0											

Client	CANMET - COAL RESEARCH LABORATORIES
Project	FOOTWALL STABILITY STUDY
Job No.	VG-03957
Drilling Contractor	DRILCOR INDUSTRIES LTD.

Remarks Piezometer & detailed log hole.
For Simplified log, see previous page.

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

SIMPLIFIED CORE LOG

Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	**86-P3**
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	7 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N	Azimuth	-
Date finished	APRIL 29, 1986			Ref. Elev.	1797.531 m.G.D.

Drilling & Casing Progress	Core Recovery (%)	R.Q.D. (%)	Depth (m)	Reduced Level (m.G.D.)	Bedding/ Foliation	Fracture Index (no./m.)	Test Results	Instru-mentation	DESCRIPTION
67.97	100	74	67.0	1730	Thin bedded @ 30-50°	-			SANDSTONE (cont'd) - fine grained, strong, fresh, med. grey.
69.49	96	95	68.0 69.0	1729		2.0			-68.7 m, bedding becomes indistinct, colour is light brown.
71.02	104	104	70.0	1728 1727		0			-by 69.5 m, bedding is apparent as before.
72.52	100	100	71.0 72.0	1726		0			END OF HOLE @ 72.52 m
29-04-86									

Client	CANMET - COAL RESEARCH LABORATORIES	Remarks	Piezometer & detailed log hole. For discontinuity data, see next page.
Project	FOOTWALL STABILITY STUDY		
Job No.	VG-03957		
Drilling Contractor	DRILCOR INDUSTRIES LTD.		

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

DETAILED DISCONTINUITY LOG

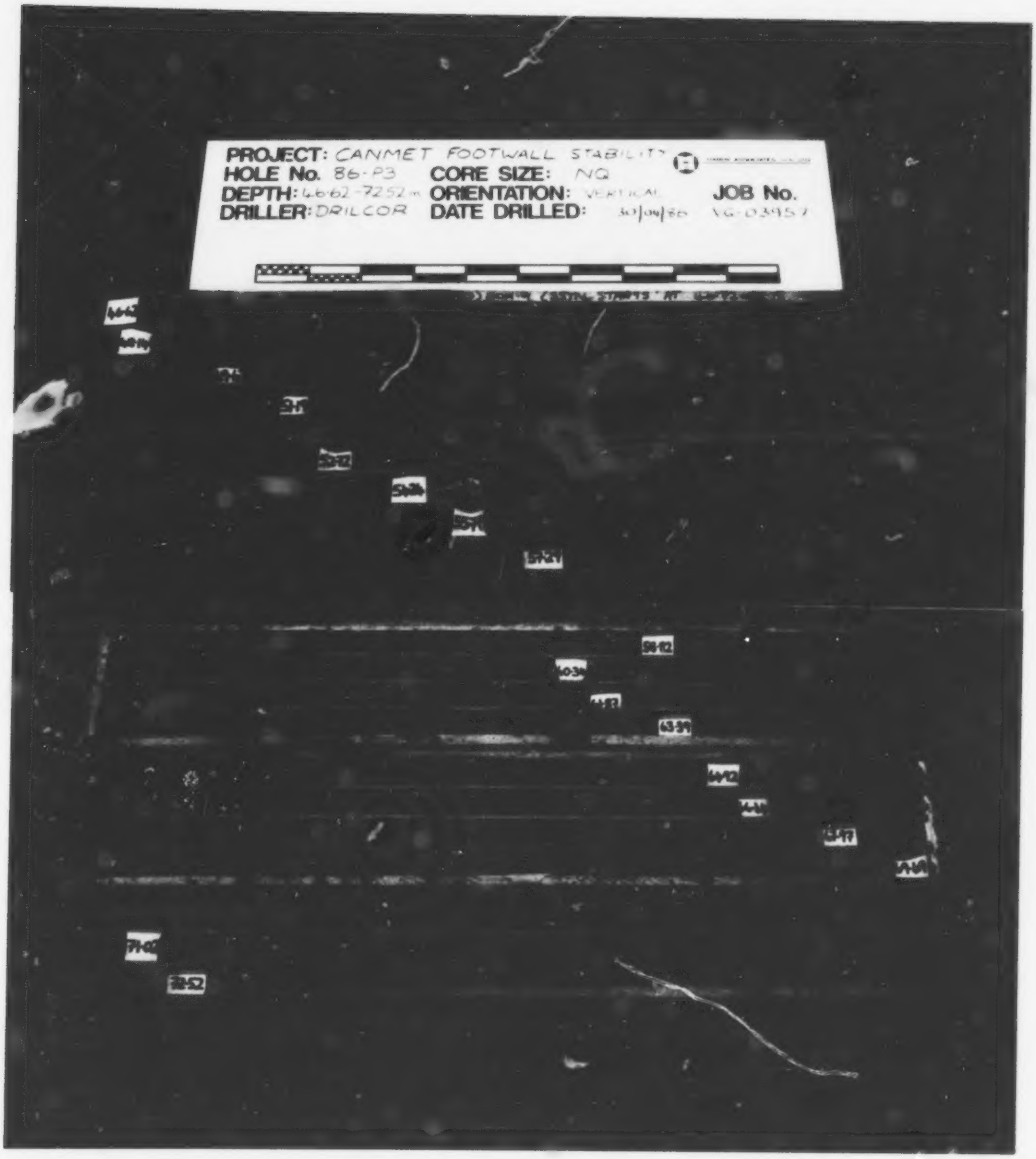
Type of Drilling	Rotary, Water-Flush, Wire-Line	Logged by	F.H. Shrimer	Drillhole No.	86-P3
Rig	Drilcor Assembled	Checked by	G.J. Baldwin	Sheet	8 of 8
Bit	NQ, Diamond	Location	Line Creek Mine	Dip	Vertical
Date started	APRIL 28, 1986	Co-ordinates	659648.956E 5533653.992N	Azimuth	-
Date finished	APRIL 29, 1986			Ref. Elev.	1797.531 m.G.D.

Depth (m)	Reduced Level (m.G.D.)	Type	Orientation		Roughness		Surface Coating	Infill Material	Gouge Width	Weathering	Comments
			Dip	∝	Descr.	i					
67.0											
66.79		JNT	35	0	IRSL	49	Coal	-	-	FR	
67.05		Fract	45	180	IRR	47	-	-	-	FR	
66.95–67.30		JNT	0-10	90	IRR	-	Gypsum	-	-	FR	
	1730										
68.0											
	1729										
68.81		Fract	45	340	PMR	16	-	-	-	FR	
69.0											
69.20		Fract	15	100	PMR	27	Clay	-	-	FR	
69.48		Fract	85	0	IPR	21	-	-	-	FR	
	1728										
70.0											
	1727										
71.02	71.0	Fract(DB?)	85	180	IRR	-	-	-	-	FR	
	1726										
72.0											
72.52					END OF HOLE @ 72.52 m						

Client	CANMET - COAL RESEARCH LABORATORIES	Remarks	Piezometer & detailed log hole. For Simplified log, see previous page.
Project	FOOTWALL STABILITY STUDY		
Job No.	VG-03957		
Drilling Contractor	DRILCOR INDUSTRIES LTD.		

HARDY ASSOCIATES (1978) LTD.

CONSULTING ENGINEERING & PROFESSIONAL SERVICES



PROJECT: CANMET FOOTWALL STABILITY
HOLE No. 86-P3 **CORE SIZE:** NQ
DEPTH: 66.62-72.52 m **ORIENTATION:** VERTICAL **JOB No.**
DRILLER: DRILCOR **DATE DRILLED:** 30/04/86 VG-03957

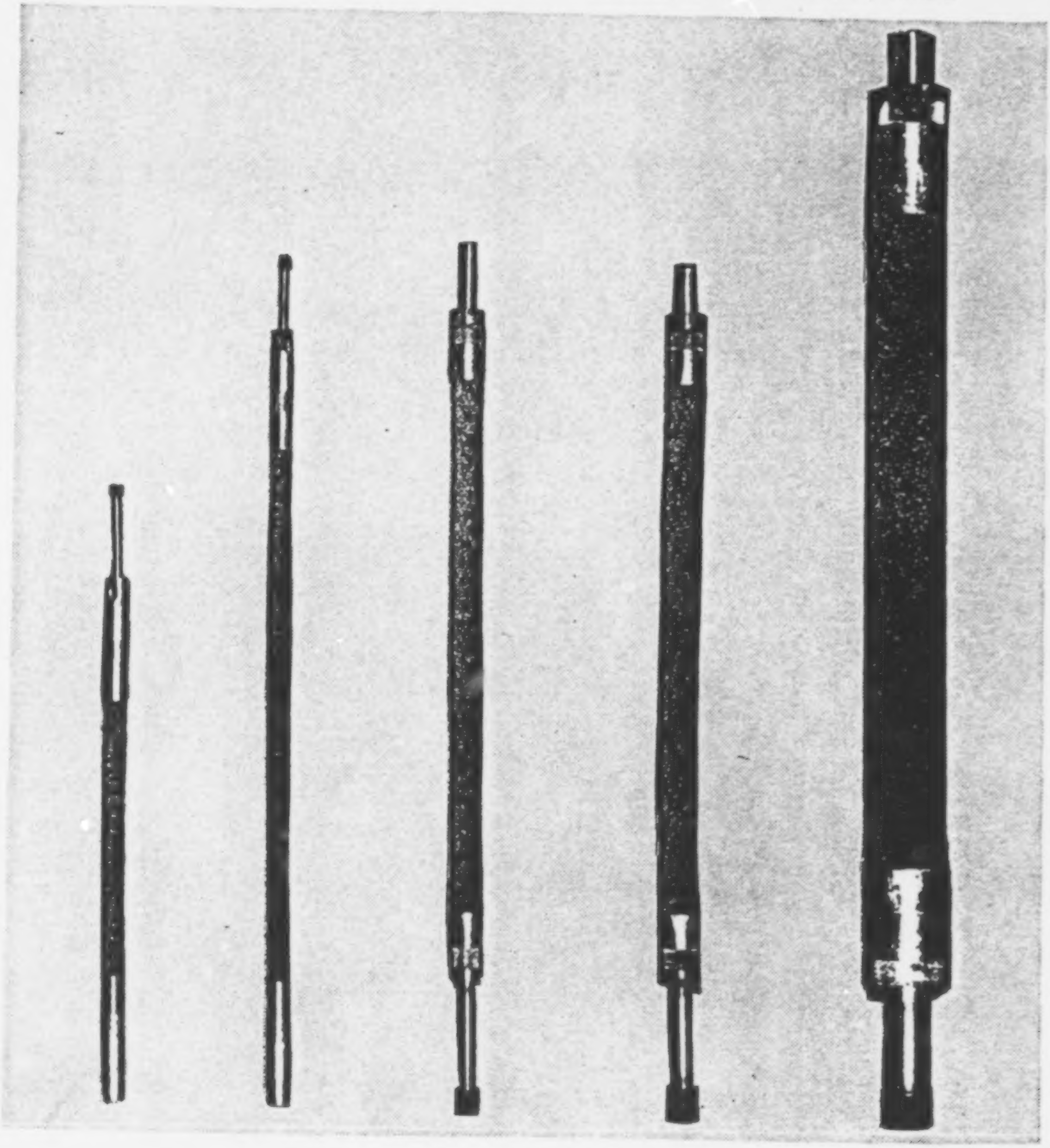
APPENDIX 'E'

ADDITIONAL DETAILS OF INSTRUMENTATION INSTALLED AND/OR USED AT LINE CREEK

R.S.T.™
INSTRUMENTS LTD.

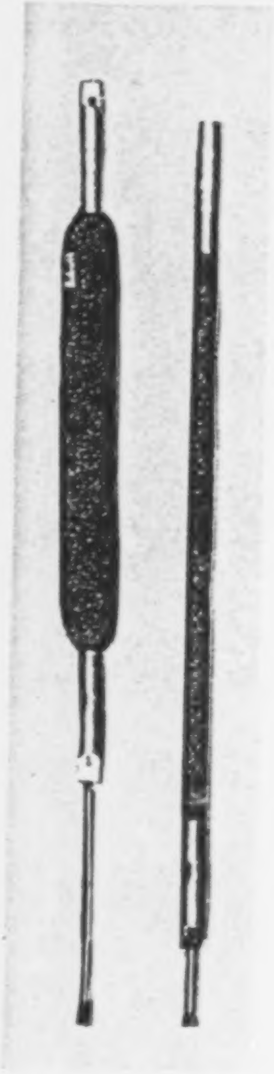
BOREHOLE PACKERS

A pneumatically or hydraulically inflatable packer incorporating a sliding head. A steel reinforced, abrasion resistant gland renders this packer virtually indestructable. Packer heads are constructed of steel or aluminum on a polished stainless steel shaft.



N-H ½ SIZE **N-H/N-Q** **H-Q** **P-Q** **1-170**

R.S.T. BOREHOLE PACKERS HAVE BEEN DEVELOPED ESPECIALLY FOR PERMEABILITY TESTING WITH ALL WIRELINE SYSTEMS



Inflated Deflated

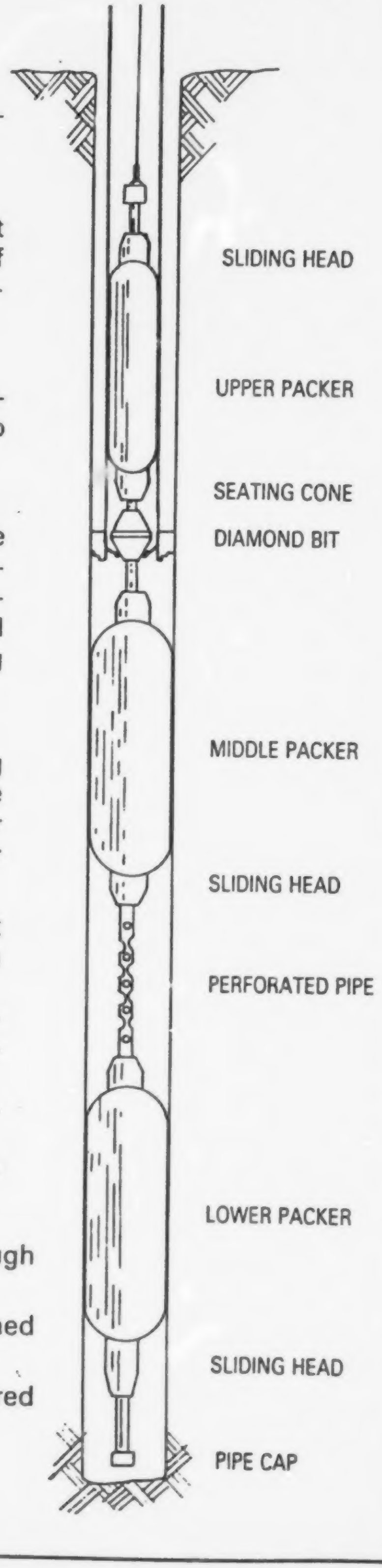
MODEL N-H

ADVANTAGES

- Requires 1/2 to 1/3 the time of conventional packer testing.
- Uses the rod string to conduct test water, eliminating the second set of rods necessary with mechanical packers.
- Minimizes in-hole disturbance and costly redrilling by eliminating the need to pull the rods for each test.
- For through-the-bit applications, the seating cone locates the packers properly in the borehole. The outside diameter clears any irregularities in the drill string, passes through the landing ring and seats in the drill bit.
- All packers are identical, maximizing inter-changeability of spares, and the versatility of allowing the packer string to be assembled in a number of combinations, as follows:

1) Triple packers; for through-the-bit straddle zone testing - shown on right.
2) Double packers; for through-the-bit testing to the bottom of the borehole.
3) Double packers; for open hole straddle zone testing.
4) Single Packer; for open hole testing to the bottom of the borehole.

- Model N-H will fit A through H series open boreholes, and through the bit in both N & H boreholes.
- Conical heads aid both insertion and removal in inclined boreholes.
- 1 metre exposed gland length provides maximum seal in fractured formations.
- Glands are easily replaceable in the field.
- Long life wiper/seal on a polished stainless steel shaft.



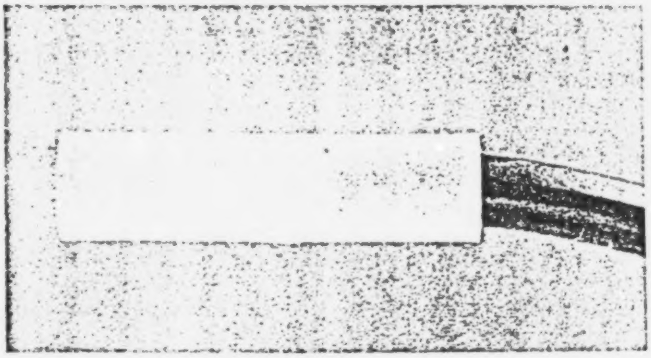
P-100 GENERAL PURPOSE PIEZOMETER

The Model P-100 is a general purpose piezometer capable of monitoring pore pressure from 3-2000 psi (21-13,800 kPa). This instrument combines the features of high accuracy and reliability, small size, low cost, and extremely low displacement (0.002 cc), with the ability to be constantly monitored.

In applications where the measurement of small or rapid changes in pore pressure is critical, this constant output capability is a definite asset.

The key to the long term reliability and accuracy lies in the simplicity of the design. There is no critical mechanical valving assembly to stick, jam, or corrode thereby rendering the piezometer inoperable. The P-100 is nonmetallic and corrosion free, both internally and externally.

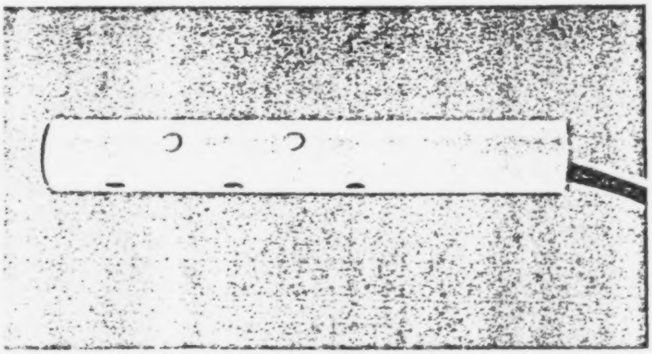
Because of the small size (0.625 in. O.D. x 2.45 in. long) (1.59 cm x 6.22 cm) multiple installations are possible in virtually any size borehole.



P-100 (Actual Size)

P-100-1 GENERAL PURPOSE PIEZOMETER

The Model P-100-1 consists of a P-100 transducer encapsulated in a sand filled, Casagrande type piezometer body. This body employs a protected 70 micron porous plastic filter and sand filter, in addition to the P-100's 50 micron stainless steel filter. The piezometer body will accept a ¾ in. PVC pipe, allowing a riser to be fitted for increased tubing protection and ease of installation. Filter area 21 in.^{2} (133 cm^2). 1.32 in. O.D. x 10.0 in. long (3.35 cm x 24.8 cm).



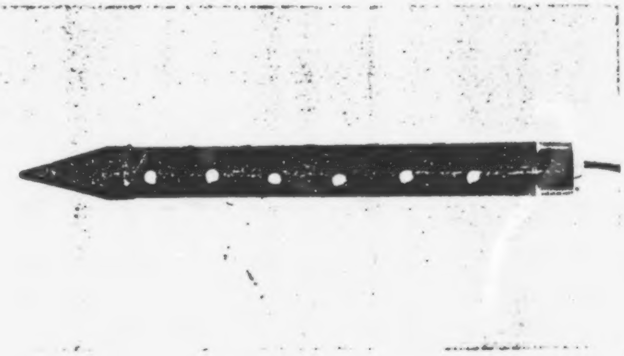
P-100-1

P-102 WELLPOINT PIEZOMETER

The Model P-102 Wellpoint piezometer has been specifically designed to withstand the forces of impact driving. This model utilizes our P-100-1 piezometer, epoxied into a perforated steel housing. There is no critical mechanical valving assembly in the P-100 and therefore no concern with installation shock and acceleration. If required this unit is capable of being constantly monitored during the installation process.

The Model P-102 is ideal for use in soft clays and cohesionless soils, as it eliminates the need to drill a hole in order to install the piezometer. They may either be driven by a non-rotating hammer or pushed directly into the soil.

The standard model utilizes a 37.69 sq. in. (245 sq. cm) porous plastic filter, having a 70 micron pore diameter. The threaded connection is 1¼" male NPT. Length 17.5 in. (44.45 cm) x 1.69 in. (4.29 cm) O.D.



P-102

R.S.T.™
INSTRUMENTS LTD.

ROD EXTENSOMETER

A low cost, convenient instrument for the monitoring of ground displacements. Designed to withstand severe field conditions and accommodate transverse shear. The unit is supplied completely assembled and sealed for grouting into the borehole. Rod displacement readings may be taken manually using a dial gauge or monitored continously with a remote readout head.

CONSTRUCTION:

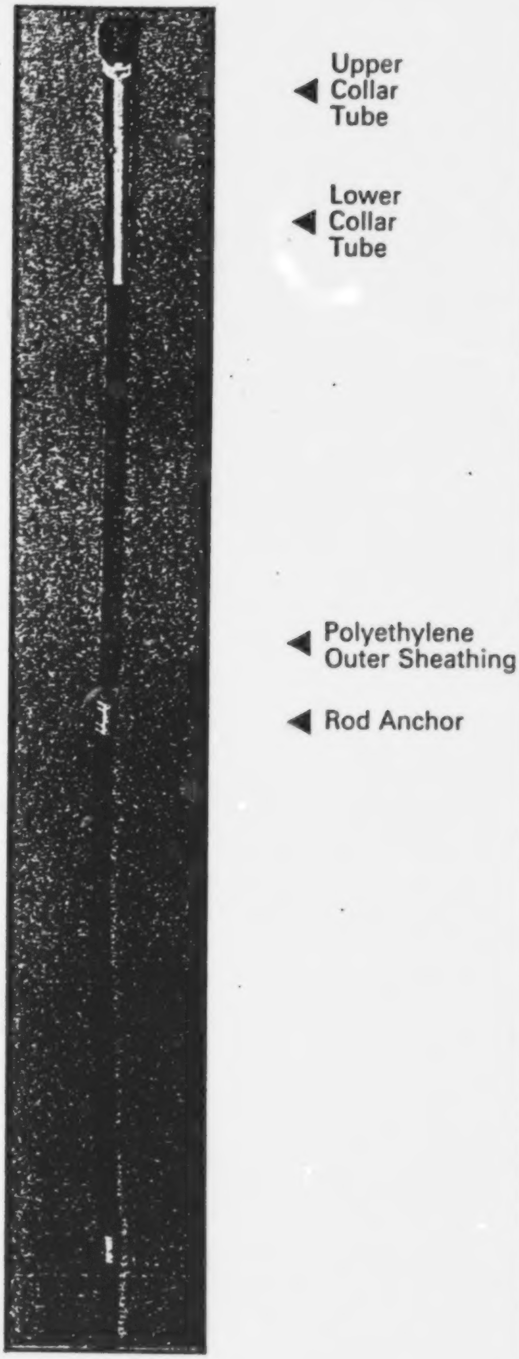
The extensometer consists of a maximum of 7 oiled spring steel rods, each sheathed in a neat fitting plastic tube. One end of each rod is connected to a ribbed steel anchor, grouted into the borehole. The other end is fitted with a brass cap which is the displacement surface with reference to the stainless steel collar tube. The sheathed rods are assembled around a compressible filler and spirally bound for rigidity. The whole assembly is finally sheathed in a polyethylene tube, sealed at each anchor point. This construction provides a void for limited transverse shearing of the borehole without the rods being jammed. Before coiling of the extensometer, the ends of the rods are locked in position at the collar and are released only after the grout has hardened in the borehole.

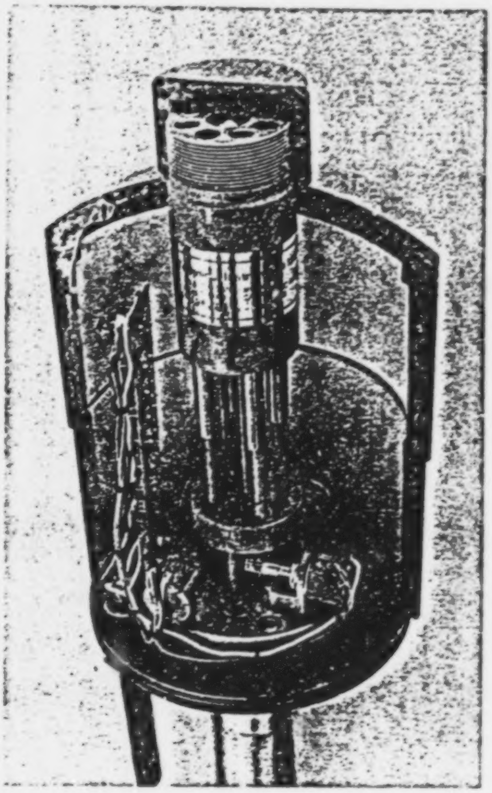
INSTALLATION:

The extensometer is supplied fully assembled in a 1.2 metre diameter coil. At the installation site, the unit is uncoiled, fitted with suitable grout and airbleed tubes, and installed into the borehole. After grout has been injected and initial set has been reached, the protective cap is removed, the rods released, and the initial displacement recorded. All collar components are of brass or stainless steel and each rod is clearly identified.

ADVANTAGES:

- Accurate at low cost,
- Rod length is virtually unlimited,
- Unit is supplied completely assembled and sealed, ready for installation,
- Assembly is light in weight and easily handled, installation is quick and simple,
- Compact design allows installation in boreholes of minimum size; up to 7 rods may be accommodated in a 60mm borehole,
- Limited transverse shear accommodated, without jamming of rods,
- Readily converted to remote readout at anytime after installation.
- The electrical head does not require a specialized readout instrument - only a power supply and digital multimeter.





FOUR CHANNEL REMOTE HEAD
WITH MANUAL OVER-RIDE ASSEMBLY

SPECIFICATIONS:

Range — 150mm (300 mm optional)

Input — 5-24 VDC

Output — 0-2.5 VDC

Resolution — 0.1mm standard
0.01 optional

Channels — 7 maximum

REMOTE READOUT HEAD:

A compact head assembly which permits all rods in an extensometer installation to be monitored continuously from a distant readout station.

SYSTEM:

Each rod drives a rotary potentiometer through a precision rack and pinion. A movement of 150mm (300mm optional) can be monitored by the linear change in voltage. The voltage output readout head has a voltage regulator and individual bridge type circuits for each sensor, enabling the readout station to be quite a distance from the extensometer heads without loss of resolution.

The heads are manufactured from brass, PVC, and stainless steel, and are completely sealed against the ingress of moisture.

The heads can be factory installed or attached to the collar in the field at any time after installation of the extensometer rod assembly.

An optional manual over-ride allows manual readings in addition to electrical readings.

The output of the head can be monitored using a simple digital multimeter or recorded on a data logger.

ORDERING INFORMATION:

- Advise if manual over-ride is required.
- Nominate number of sensors required.
- Specify if optional resistance output is required.
- Advise length of cable required and plug types etc.
- Advise if 150 mm or 300 mm range.

READOUT UNITS

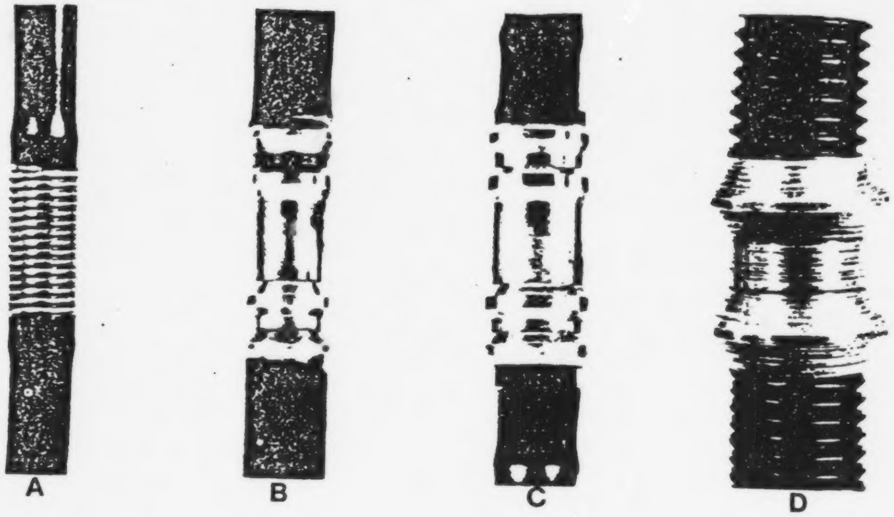
Voltage output, remote readout extensometers can be monitored with any high accuracy, digital multimeter, using an external DC power supply.

A display unit is available with these features:

- Digital display, reading directly in mm (to 0.1mm).
- Heavy duty, rechargeable battery for continuous monitoring in excess of 8 hours.
- Selector switch for up to 7 channels.
- Heavy duty sealed case with lockable lid.
- Junction box facilities for multiple sensor installations on special order.

TECHNICAL DETAILS:

ROD ASSEMBLIES:



					RECOMMENDED			
Rod assembly type	A		B		C		D	
Anchor diam.(mm)	25		33		41		65	
Details	Nominal Borehole diam.(mm)	Maximum Number of Rods	Nominal Borehole diam.(mm)	Maximum Number of Rods	Nominal Borehole diam.(mm)	Maximum Number of Rods	Nominal Borehole diam.(mm)	Maximum Number of Rods
UPHOLE With external air bleed tube 10mm I.D.	45	4	51	5	60	7	85	7*
DOWNHOLE With external grout tube 15mm I.D. **	51	4	57	5	65	7	90	7*
UPHOLE With internal air bleed tube 10mm I.D. ***	32	3	38	3	45	5	75	7
DOWNHOLE With internal grout tube 10mm I.D. ****	N/A	N/A	38	3	45	5	75	7

Notes:

* Up to 19 rods can be used with special collar assembly (shear accommodation is substantially reduced).

** Use 20mm grout tube if possible, particularly for extensometers longer than 30 metres.

*** Type A. assembly has airbleed tube 4.5mm I.D. only, not recommended for extensometers longer than 15 metres.

**** Not recommended for extensometers longer than 20 metres.

TECHNICAL DETAILS (CONTINUED)

COLLAR ASSEMBLY

The stainless steel collar assembly has four features:

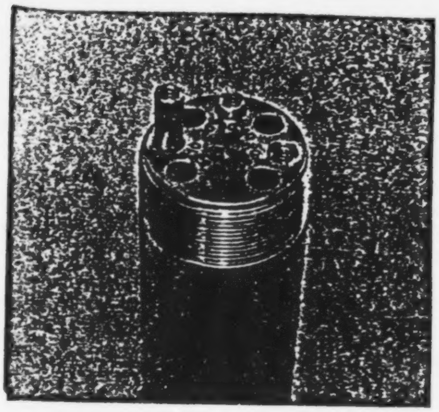
(1) A machined reference surface, protected by a heavy PVC cap.

(2) The rod guide tubes and outer sheath are securely anchored in epoxy resin.

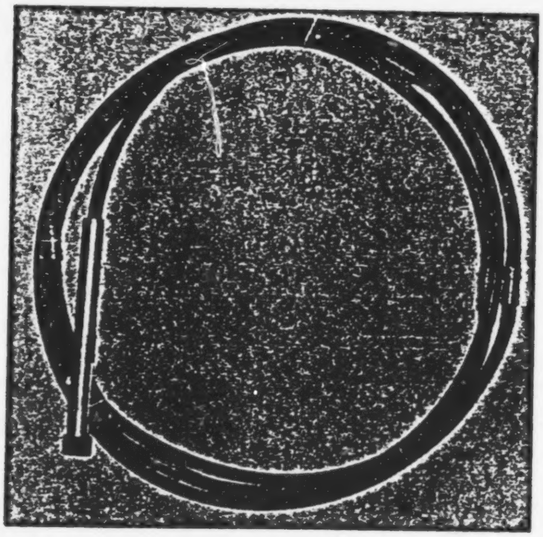
(3) A remote readout head can be fitted to any installed extensometer by removing the cap and making a simple threaded connection to each rod.

(4) Rods individually sheathed in brass guide tubes.

Collar assembly dimensions are 550 x 48mm diameter. The borehole should be reamed to 75mm diameter x 700mm deep to accommodate the collar assembly plus grout and air bleed tubes.



MANUAL COLLAR ASSEMBLY



MANUAL EXTENSOMETER AS SHIPPED

ORDERING INFORMATION:

- Nominate number of rods and length of each from the collar.
- Specify range required when in excess of 150mm.
- Specify anchor type.
- Confirm if grout and air bleed tubes are to be fitted to extensometers or supplied separately.
- Specify range of axial displacement to be accommodated.
- Advise if dial gauge is required.
- Indicate if excessive transverse shear is likely or expected.
- Advise if manual or electrical head.

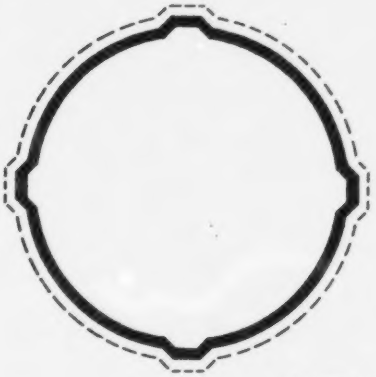
Manufactured under exclusive licence for Geosystems, Australia, by:

R.S. TECHNICAL INSTRUMENTS LTD.
No. 18 - 1780 McLean Avenue,
Port Coquitlam, B.C. Canada V3C 4K9
Telephone (604) 941-9155 / 941-4848

Represented by:

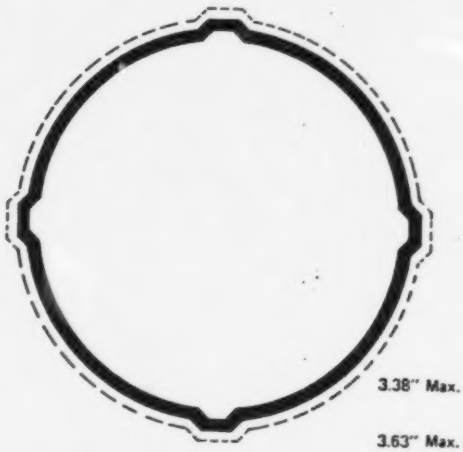
PRINTED IN CANADA

Aluminum Casing



2.79" Max. O.D. x 0.080" Wall
Aluminum Casing

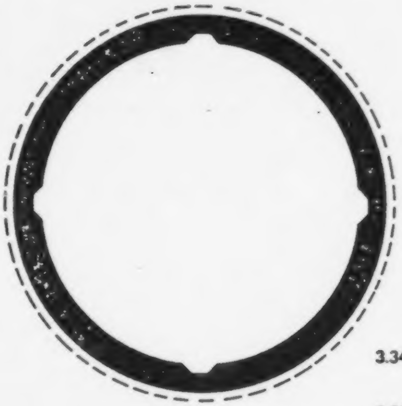
2.94" Max. O.D. x 0.080" Wall
Aluminum Coupling



3.38" Max. O.D. x 0.093" Wall
Aluminum Casing

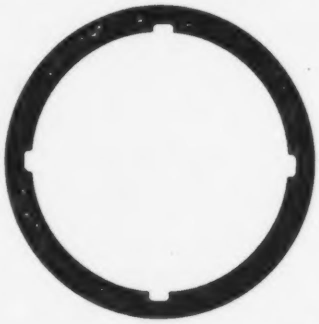
3.63" Max. O.D. x 0.093" Wall
Aluminum Coupling

Plastic Casing



3.34" O.D. x 2.87" I.D.
ABS Plastic Casing

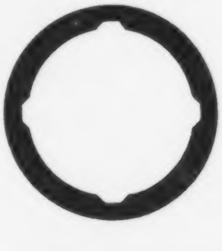
3.50" O.D. x 3.20" I.D.
ABS Plastic Coupling



2.75" O.D. x 2.32" I.D.
ABS Plastic Casing

2.75" O.D. x 2.55" I.D.
ABS Plastic Coupling

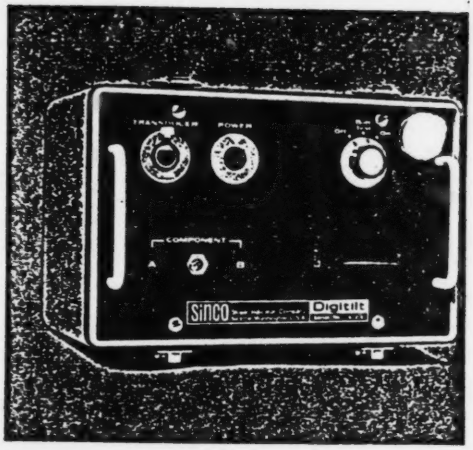
2.87" O.D. x 2.67" I.D.
ABS Plastic Telescoping Coupling



1.90" O.D. x 1.50" I.D.
ABS Plastic Casing
Self Coupling

DIGITILT® Inclinometer

- Sensitivity of one part in 10,000
- Field-proven reliability
- Easy to operate
- Reads out directly in displacement
- Can be used in small diameter boreholes
- Automatic recording capability



Knowing both rate and location of lateral earth movement is critical to evaluating the performance and safety of structures and natural slopes. The Digitilt® Inclinometer System is used to measure these critical lateral movements in dams, embankments, slopes and landslides. The system has been used to monitor movement at numerous sites throughout the world ranging from Tarbela Dam in Pakistan, Mica Dam in British Columbia, China Steel Mills in Taiwan, to Climax Molybdenum in Colorado.

To determine subsurface lateral movements, grooved casing is installed in a borehole to a depth below the anticipated zone of movement. The grooves control the orientation (direction) of the sensor which is lowered through the casing to obtain initial readings at specified depths (at two foot intervals, for example). Periodic readings at these depths then provide data on the location, magnitude, direction and rate of movement of the casing.

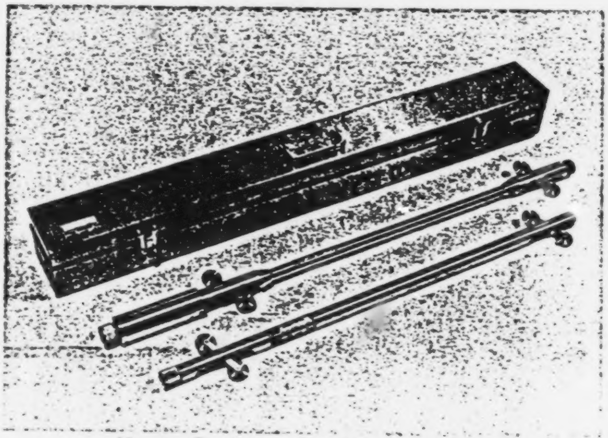
The Digitilt® System is designed to provide overall sensitivity of ±.0001 foot lateral movement per two feet of casing or ±.02mm lateral movement per 500mm of casing. Using Slope Indicator Company casing, properly installed and within 1° (.018 rad) of vertical, the Digitilt® total system accuracy is .10 inch per 100 feet (2mm per 25 meters) of casing. For casing installation within 3° (.053 rad) of vertical, the accuracy is .3 inch per 100 feet (6mm per 25 meters).

Sensors

The biaxial sensors Models 50320 and 50325 have two servo-accelerometers in a waterproof housing. One accelerometer has its sensing axis in the plane of the spring-loaded wheels which ride in the casing grooves. The second accelerometer has its sensing axis at 90° (π/2 rad), so that the angle of inclination of sensor and casing is measured in the two orthogonal directions (both north-south and east-west components are measured).

The accelerometers are force balanced, servo type and provide a rapid stabilized response to tilt by changing the current flow through the restoring coil. The resulting voltage output is proportional to the sine of the angle of inclination of the long axis of the sensor from the vertical. The voltage is positive for positive angles of inclination and negative for negative angles. The output voltage is stable with respect to temperature, cable resistance and input voltage variations. The standard Digitilt® System will operate through ±30° (π/6 rad) from the vertical. Using optional 1.0g accelerometers, this range may be expanded to ±90° (π/2 rad). The metric Digitilt® system will operate through ±23° (.40 rad) from the vertical (±53° [.92 rad] with some Indicators).

See Table 2 for sensor specifications.

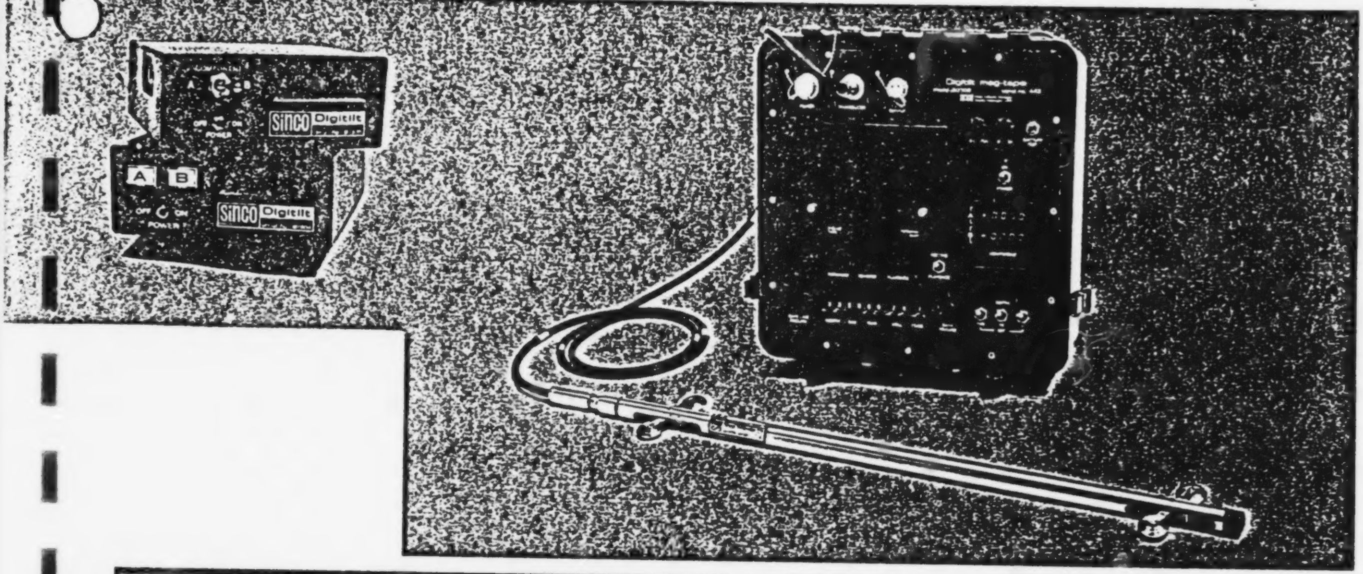


Upper: Stainless Steel Carrying Case
Center: Model 50320 Sensor Lower: Model 50325 Sensor

Indicators

The portable, rugged Digitilt® Indicators utilize digital displays with automatic polarity (direction) signs. Indicators operate on rechargeable internal batteries, external 12-volt battery, or 110/230 VAC line power.

Table 1 lists the various indicators. Model 50304,



Left: Model 50304 Indicator
Center: Model 50306 Indicator, Upper w/Toggle Switching, Lower w/Pushbutton Switching
Bottom: Model 50308 Mag-Tape Indicator w/Control Cable & Model 50325 Sensor

INDICATOR MODEL	DIMENSION	WEIGHT	POWER INTERNAL	POWER EXTERNAL	CHARGER	OPER TIME ON BATT.	DIGITAL DISPLAY	RECORDING CAPABILITY
50309	5x7x7 in (12.7x17.8x17.8 cm)	7.5 lb (3.4kg)	6V, 6Ah	12VDC/ Charger	External	12 hrs**	4 digit LCD	Manual
50306	5.6x2.4x9 in (14.3x6x22.9 cm)	5 lb (2.3kg)	6V, 6Ah	6VDC/ Charger	External	8 hrs	4 digit LED	Manual
50304	10x7x7 in (25.4x17.8x17.8 cm)	11lb (5kg)	6V, 8Ah	110 VAC/ 12 VDC	Internal	10 hrs	4 digit LED	Manual
50308	10.5x15x15 in (26.7x38x38 cm)	35 lb (15.9kg) 40° lb (18.1kg)	6V, 10Ah 6V, 20Ah*	110 VAC/ 12VDC	Internal	8 hrs 16 hrs *	4 digit (A/B) 3 digit (Depth)	Integral Cassette Recorder

Table 1 — Indicators

*Optional battery pack will double operating time and add 5 lbs (2.3kg)

**Below 40°F ambient, operating time is reduced by up to 50% to keep display warm

50306 and 50309 are the standard portable field indicators. Model 50306 incorporates the latest electronics to minimize size yet maintain ruggedness. Model 50304 combines the electronics of the 50306 with an internal battery charger in a small portable case. The 50309 features a liquid crystal display and is environmentally packaged. Mag-tape model 50308 automatically records data on an integral cassette recorder and is environmentally packaged to permit operation under adverse weather conditions.

Cable

In the Digitilt® system, the sensor and indicator are connected with a 0.42-inch (10.7mm) diameter cable which carries the signal and acts as the suspension cable for lowering the sensor into the borehole. The cable has a stranded steel core to bear pulling stresses and eliminate connector and wire breakage. The cable is jacketed with heavy waterproof neoprene and marked externally at one-foot or half-meter intervals for easy depth determination. Metric cables are available on request. Adhesive layers between the stranded steel core, individual wires and the neoprene jacket prevent jacket creep and slippage when the cable is clamped or held by the outer jacket.

Slope Indicator Casing

The casing used for inclinometer readings has four lengthwise grooves spaced at 90° ($\pi/2$ rad) on the inside circumference. These grooves are for guiding the wheels of the inclinometer sensor in the two orthogonal directions of measurement. It is by means of these guide grooves, which control orientation of the sensor, that lateral earth measurements can be measured with a high degree of sensitivity and accuracy.

Slope Indicator casing is available in ABS plastic in three sizes: 3.34" (84.8mm) O.D., 2.75" (69.9mm) O.D., and 1.9" (48.3mm) O.D. Epoxy-coated or uncoated aluminum alloy casing is available in two sizes: 3.38" (85.9mm) O.D. and 2.79" (70.9mm) O.D. The casing has standard lengths of either five feet (1.53m) or ten feet (3.05m). Couplings at the joints are for butt joints or telescoping joints. In situations where large vertical settlements occur, the telescoping joints prevent buckling of the casing.

Vertical Earth Movement

Vertical Earth movements - settlement or heave of foundations and embankments - can also be measured in the slope indicator casing with telescoping joints. This is done by means of a settlement probe and surveyor's tape measuring to each joint in the casing or with a SONDEX Probe and surveyors tape measuring to rings installed around the casing.

Casing Spiral Survey

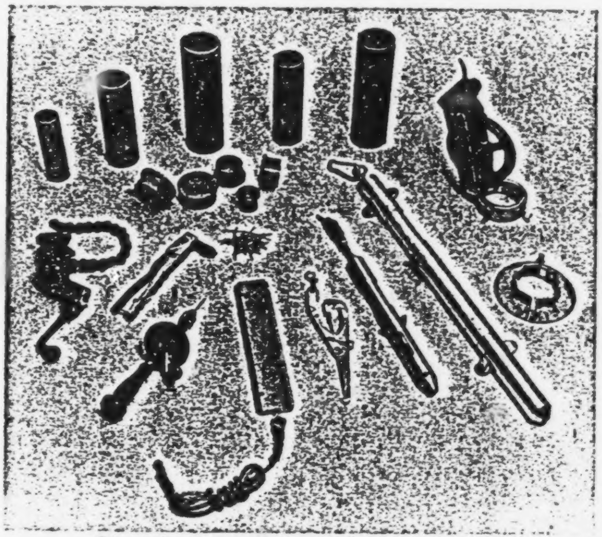
Spiral Checking Instruments are available for rent or purchase for determining the accumulated spiral of a casing from top to bottom as well as at intermediate points. SINCO casing has less than 1° (.018 rad) of spiral per 10-feet (3.05m) when properly installed. However, if a closer determination of spiral is required or if improper casing installation is suspected, the SINCO Spiral Checking Instrument can provide an accuracy of 10 min. of spiral per 5-feet surveyed (.003 rad of spiral per 1.53 meters).

Experience and Field Service

Our staff has over 21 years experience in the installation of inclinometer systems under all field conditions. We can give recommendations on casing types, installation methods, monitoring techniques, data reduction and presentation methods. We can also provide field services for training clients' personnel in all methods of installation, monitoring and field maintenance of the equipment.

Call on the Slope Indicator Company when you need to monitor horizontal displacements, determine pile tip locations after driving, or pile bending under test loads. Sensors can be adapted with special wheel carriages to internally survey pipe piles for their installed profiles or to survey drill rods to locate drill bits and to determine heading direction. Special torque rods are available to control sensor orientation while surveying pipe piles and drill rods.

Since this is a scientific instrument, measurements should be taken, recorded, and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of the personnel used.



Slope Indicator Casing and Accessories

SENSOR	MODEL 50320	50325	MODEL 50320-J	50325-J
Sensitivity	± .0001 foot per 2 feet casing	(same)	± .02mm per 500mm casing	(same)
Total System Accuracy	± 0.3 inch per 100 feet casing	(same)	± 6mm per 25 meter casing	(same)
Wheel Base	24 inches	(same)	500mm	(same)
Overall Length	36.5 inches	30 inches	81.6cm	65.3cm
Outside Diameter, not including wheels	1.69 inches	1.0 inch	42.9mm	25.4mm
Sensors	Two 0.5g closed loop force-balanced servo-accelerometers	(same)	(same)	(same)
Operating Range	0° to 30° (π/6 rad) 0° to 90° (π/2 rad) Special	(same)	0° to 53° (.92 rad) 0° to 90° (π/2 rad) Special	(same)
Cable	0.42-inch O.D., six conductor with 1/16-inch stranded-steel core; waterproof neoprene cover with external marks at one-foot intervals		10.7mm O.D. six conductor with 1.59mm stranded-steel core; waterproof neoprene cover with external marks at 500mm intervals	
Casing	All sizes except 1.9" O.D.	All sizes	All sizes except 48.3mm O.D.	All sizes

Table 2 — Specifications

SINCO
Slope Indicator Company
3668 Albion Place North, Seattle, Washington 98103 U.S.A.
TWX: 910-444-2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073

Printed in USA (4-79)

APPENDIX 'F'

RESULTS OF INCLINOMETER MONITORING AT LINE CREEK

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              JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                            (Calculated from the bottom of the installation and
             based on the resultant of both the"A" and "B" components of slope change)


              TILTMETER INSTALLATION:86I1                 DEPTH:   2FT. -  82FT.

              AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                              MM/DD/YYYY   MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 5  8 1986    5 16 1986
DEPTH(FT.)                                                                        +            *
          -1.50     -1.00      -.50       .00       .50      1.00      1.50
           IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
          2 I                           I*                            I          .000         .083
          4 I                           I*                            I          .000         .088
          6 I                           I*                            I       .  .000         .088
          8 I                           I*                            I          .000         .089
         10 I                           I*                            I          .000         .085
         12 I                           I*                            I          .000         .085
         14 I                           I*                            I          .000         .085
         16 I                           I*                            I          .000         .086
         18 I                           I*                            I          .000         .086
         20 I                           I*                            I          .000         .085
         22 I                           I*                            I          .000         .083
         24 I                           I*                            I          .000         .083
         26 I                           I*                            I          .000         .083
         28 I                           I*                            I          .000         .082
         30 I                           I*                            I          .000         .081
         32 I                           I*                            I          .000         .081
         34 I                           I*                            I          .000         .080
         36 I                           I*                            I          .000         .078
         38 I                           I*                            I          .000         .076
         40 I                           I*                            I          .000         .072
         42 I                           I*                            I          .000         .068
         44 I                           I*                            I          .000         .056
         46 I                           I*                            I          .000         .053
         48 I                           I*                            I          .000         .050
         50 I                           I                             I          .000         .047
         52 I                           I                             I          .000         .044
         54 I                           I                             I          .000         .041
         56 I                           I                             I          .000         .038
         58 I                           I                             I          .000         .037
         60 I                           I                             I          .000         .035
         62 I                           I                             I          .000         .029
         64 I                           I                             I          .000         .025
         66 I                           I                             I          .000         .022
         68 I                           I                             I          .000         .019
         70 I                           I                             I          .000         .016
         72 I                           I                             I          .000         .015
         74 I                           I                             I          .000         .012
         76 I                           I                             I          .000         .008
         78 I                           I                             I          .000         .005
         80 I                           I                             I          .000         .003
         82 I                           I                             I          .000         .000
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                  JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING

       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                              (Calculated from the bottom of the installation and
              based on the resultant of both the"A" and "B" components of slope change)


                 TILTMETER INSTALLATION:86I1                    DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:       0. DEGREES             INITIAL DATA RECORDED:  5  8 1986

                                                                                MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 5 16 1966   5 23 1986
DEPTH(FT.)                                                                          +         *
          -1.50     -1.00      -.50       .00       .50      1.00     1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                            *I +                           I          .083     -.004
           4 I                            *I +                           I          .088     -.001
           6 I                             I +                           I          .088      .001
           8 I                             I +                           I          .089      .005
          10 I                             I +                           I          .085      .002
          12 I                             I +                           I          .085      .003
          14 I                             I +                           I          .085      .005
          16 I                             I +                           I          .086      .006
          18 I                             I +                           I          .086      .006
          20 I                             I +                           I          .085      .007
          22 I                             I +                           I          .083      .006
          24 I                             I +                           I          .083      .007
          26 I                             I +                           I          .083      .008
          28 I                             I +                           I          .082      .009
          30 I                             I +                           I          .081      .008
          32 I                             I +                           I          .081      .010
          34 I                             I +                           I          .080      .011
          36 I                             I +                           I          .078      .011
          38 I                             I +                           I          .076      .011
          40 I                             I+                            I          .072      .011
          42 I                             I+                            I          .068      .011
          44 I                             I+                            I          .056      .001
          46 I                             I+                            I          .053      .000
          48 I                             I+                            I          .050      .001
          50 I                             I+                            I          .047      .001
          52 I                             I+                            I          .044      .002
          54 I                            *I+                            I          .041     -.001
          56 I                             I+                            I          .038      .000
          58 I                             I+                            I          .037      .001
          60 I                             I+                            I          .035      .002
          62 I                            *I+                            I          .029     -.002
          64 I                            *I+                            I          .025     -.002
          66 I                            *I                             I          .022     -.003
          68 I                            *I                             I          .019     -.001
          70 I                            *I                             I          .016     -.001
          72 I                             I                             I          .015      .001
          74 I                            *I                             I          .012     -.003
          76 I                            *I                             I          .008     -.004
          78 I                            *I                             I          .005     -.002
          80 I                            *I                             I          .003     -.002
          82 I                             I                             I          .000      .000
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              JOB NUMBER  VG03957          LINE CREEK MINE: FOOTWALL MONITORING


       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                            (Calculated from the bottom of the installation and
            based on the resultant of both the"A" and "B" components of slope change)



               TILTMETER INSTALLATION:86I1                    DEPTH:   2FT. -  82FT.

               AZIMUTH OF GROOVE 1-3:       0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                               MM/DD/YYYY    MM/DD/YYYY
           CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 5 23 1986    5 27 1986
DEPTH(FT.)                                                                         +            #
          -1.50    -1.00     -.50      .00      .50     1.00     1.50
           IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
         2 I                           I                           I          -.004         .014
         4 I                           I                           I          -.001         .017
         6 I                           I                           I           .001         .014
         8 I                           I                           I           .005         .019
        10 I                           I                           I           .002         .015
        12 I                           I                           I           .003         .017
        14 I                           I                           I           .005         .019
        16 I                           I                           I           .006         .021
        18 I                           I                           I           .006         .022
        20 I                           I                           I           .007         .023
        22 I                           I                           I           .006         .025
        24 I                           I                           I           .007         .026
        26 I                           I                           I           .008         .028
        28 I                           I                           I           .008         .029
        30 I                           I                           I           .008         .029
        32 I                           I                           I           .010         .031
        34 I                           I                           I           .011         .032
        36 I                           I                           I           .011         .033
        38 I                           I                           I           .011         .033
        40 I                           I                           I           .011         .032
        42 I                           I                           I           .011         .032
        44 I                           I                           I           .001         .019
        46 I                           I                           I           .000         .017
        48 I                           I                           I           .001         .017
        50 I                           I                           I           .001         .017
        52 I                           I                           I           .002         .018
        54 I                           I                           I          -.001         .019
        56 I                           I                           I           .000         .019
        58 I                           I                           I           .001         .018
        60 I                           I                           I           .002         .017
        62 I                           I                           I          -.002         .011
        64 I                           I                           I          -.002         .009
        66 I                           I                           I          -.003         .008
        68 I                           I                           I          -.001         .007
        70 I                           I                           I          -.001         .006
        72 I                           I                           I           .001         .005
        74 I                           I                           I          -.003         .003
        76 I                           I                           I          -.004         .001
        78 I                           I                           I          -.002         .001
        80 I                          *I                           I          -.002        -.002
        82 I                           I                           I           .000         .000
```

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                   JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                             (Calculated from the bottom of the installation and
             based on the resultant of both the"A" and "B" components of slope change)



                  TILTMETER INSTALLATION:8611                     DEPTH:   2FT. -  82FT.

                  AZIMUTH OF GROOVE 1-3:       0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 5 27 1986    5 30 1986
DEPTH(FT.)                                                                           +          *
           -1.50    -1.00      -.50        .00       .50     1.00      1.50
            IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
          2 I                              I*                            I            .014       .098
          4 I                              I *                           I            .017       .101
          6 I                              I*                            I            .014       .094
          8 I                              I*                            I            .019       .095
         10 I                              I*                            I            .015       .089
         12 I                              I*                            I            .017       .089
         14 I                              I*                            I            .019       .089
         16 I                              I*                            I            .021       .089
         18 I                              I*                            I            .022       .088
         20 I                              I*                            I            .023       .088
         22 I                              I*                            I            .025       .086
         24 I                              I*                            I            .026       .087
         26 I                              I*                            I            .028       .088
         28 I                              I*                            I            .029       .087
         30 I                              I*                            I            .029       .086
         32 I                              I*                            I            .031       .086
         34 I                              I*                            I            .032       .086
         36 I                              I*                            I            .033       .084
         38 I                              I*                            I            .033       .082
         40 I                              I*                            I            .032       .079
         42 I                              I*                            I            .032       .077
         44 I                              I*                            I            .019       .062
         46 I                              I*                            I            .017       .059
         48 I                              I*                            I            .017       .057
         50 I                              I*                            I            .017       .055
         52 I                              I*                            I            .018       .053
         54 I                              I*                            I            .019       .050
         56 I                              I                             I            .019       .048
         58 I                              I                             I            .018       .046
         60 I                              I                             I            .017       .043
         62 I                              I                             I            .011       .035
         64 I                              I                             I            .009       .032
         66 I                              I                             I            .008       .029
         68 I                              I                             I            .007       .026
         70 I                              I                             I            .006       .023
         72 I                              I                             I            .005       .020
         74 I                              I                             I            .003       .014
         76 I                              I                             I            .001       .011
         78 I                              I                             I            .001       .008
         80 I                              I                             I           -.002       .005
         82 I                              I                             I            .000       .000
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                JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


   CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                        (Calculated from the bottom of the installation and
          based on the resultant of both the"A" and "B" components of slope change)



                TILTMETER INSTALLATION:86I1                  DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 5 30 1986    6  4 1986
DEPTH(FT.)                                                                          +          *
          -1.50     -1.00     -.50      .00       .50       1.00     1.50
           IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
         2 I                         I +                       I          .098       .023
         4 I                         I +                       I          .101       .029
         6 I                         I +                       I          .094       .019
         8 I                         I +                       I          .095       .023
        10 I                         I +                       I          .089       .020
        12 I                         I +                       I          .089       .023
        14 I                         I +                       I          .089       .026
        16 I                         I +                       I          .089       .029
        18 I                         I +                       I          .088       .031
        20 I                         I +                       I          .088       .034
        22 I                         I +                       I          .086       .034
        24 I                         I +                       I          .087       .037
        26 I                         I +                       I          .088       .039
        28 I                         I +                       I          .087       .040
        30 I                         I +                       I          .086       .041
        32 I                         I +                       I          .086       .044
        34 I                         I +                       I          .086       .044
        36 I                         I +                       I          .084       .046
        38 I                         I +                       I          .082       .047
        40 I                         I +                       I          .079       .049
        42 I                         I +                       I          .077       .049
        44 I                         I+                        I          .062       .026
        46 I                         I+                        I          .059       .025
        48 I                         I+                        I          .057       .025
        50 I                         I+                        I          .055       .025
        52 I                         I+                        I          .053       .025
        54 I                         I+                        I          .050       .026
        56 I                         I+                        I          .048       .025
        58 I                         I+                        I          .046       .024
        60 I                         I+                        I          .043       .023
        62 I                         I+                        I          .035       .016
        64 I                         I+                        I          .032       .015
        66 I                         I+                        I          .029       .012
        68 I                         I+                        I          .026       .010
        70 I                         I                         I          .023       .008
        72 I                         I                         I          .020       .008
        74 I                         I                         I          .014       .004
        76 I                         I                         I          .011       .001
        78 I                         I                         I          .008       .001
        80 I                        *I                         I          .005      -.002
        82 I                         I                         I          .000       .000
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                 JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING

       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                              (Calculated from the bottom of the installation and
              based on the resultant of both the"A" and "B" components of slope change)


                 TILTMETER INSTALLATION:86I                      DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:        0. DEGREES            INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY   MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 6  4 1986     6  9 1986
DEPTH(FT.)                                                                           +          *
           -1.50     -1.00      -.50       .00       .50      1.00     1.50
              IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
            2 I                             I    *                        I         .023       .277
            4 I                             I+   *                        I         .029       .275
            6 I                             I    *                        I         .019       .258
            8 I                             I    *                        I         .023       .255
           10 I                             I   *                         I         .020       .243
           12 I                             I   *                         I         .023       .239
           14 I                             I+  *                         I         .026       .236
           16 I                             I+  *                         I         .029       .232
           18 I                             I+  *                         I         .031       .228
           20 I                             I+  *                         I         .034       .224
           22 I                             I+  *                         I         .034       .217
           24 I                             I+  *                         I         .037       .212
           26 I                             I+  *                         I         .039       .209
           28 I                             I+  *                         I         .040       .202
           30 I                             I+ *                          I         .041       .197
           32 I                             I+ *                          I         .044       .194
           34 I                             I+ *                          I         .044       .193
           36 I                             I+ *                          I         .046       .186
           38 I                             I+ *                          I         .047       .181
           40 I                             I+ *                          I         .049       .176
           42 I                             I+ *                          I         .049       .169
           44 I                             I+*                           I         .026       .134
           46 I                             I *                           I         .025       .126
           48 I                             I *                           I         .025       .121
           50 I                             I *                           I         .025       .116
           52 I                             I+*                           I         .025       .112
           54 I                             I*                            I         .026       .095
           56 I                             I*                            I         .025       .092
           58 I                             I*                            I         .024       .086
           60 I                             I*                            I         .023       .081
           62 I                             I*                            I         .016       .071
           64 I                             I*                            I         .015       .061
           66 I                             I*                            I         .012       .053
           68 I                             I                             I         .010       .047
           70 I                             I                             I         .008       .041
           72 I                             I                             I         .008       .041
           74 I                             I                             I         .004       .017
           76 I                             I                             I         .001       .010
           78 I                             I                             I         .001       .009
           80 I                             I                             I        -.002       .003
           82 I                             I                             I         .000       .000
```

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                   JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


        CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                               (Calculated from the bottom of the installation and
               based on the resultant of both the'A' and 'B' components of slope change)



                   TILTMETER INSTALLATION:86I1                      DEPTH:   2FT. - 82FT.

                   AZIMUTH OF GROOVE 1-3:       0. DEGREES            INITIAL DATA RECORDED:  5  8 1986

                                                                                   MM/DD/YYYY    MM/DD/YYYY
             CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 6  9 1986    6 12 1986
DEPTH(FT.)                                                                            +          #
            -1.50    -1.00       -.50       .00       .50      1.00      1.50
              IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
            2 I                             I     +                       I           .277       .026
            4 I                             I     +                       I           .275       .028
            6 I                             I    +                        I           .258       .014
            8 I                             I    +                        I           .255       .014
           10 I                             I    +                        I           .243       .011
           12 I                             I    +                        I           .239       .012
           14 I                             I    +                        I           .236       .016
           16 I                             I    +                        I           .232       .017
           18 I                             I    +                        I           .228       .019
           20 I                             I   +                         I           .224       .028
           22 I                             I   +                         I           .217       .028
           24 I                             I   +                         I           .212       .029
           26 I                             I   +                         I           .209       .031
           28 I                             I   +                         I           .202       .031
           30 I                             I   +                         I           .197       .032
           32 I                             I   +                         I           .194       .035
           34 I                             I   +                         I           .193       .043
           36 I                             I   +                         I           .186       .041
           38 I                             I   +                         I           .181       .043
           40 I                             I   +                         I           .176       .044
           42 I                             I  +                          I           .169       .045
           44 I                             I  +                          I           .134       .017
           46 I                             I  +                          I           .126       .016
           48 I                             I +                           I           .121       .018
           50 I                             I +                           I           .116       .019
           52 I                             I +                           I           .112       .022
           54 I                             I +                           I           .095       .010
           56 I                             I +                           I           .092       .014
           58 I                             I +                           I           .086       .015
           60 I                             I +                           I           .081       .016
           62 I                             I+                            I           .071       .009
           64 I                             I+                            I           .061       .008
           66 I                             I+                            I           .053       .007
           68 I                             I+                            I           .047       .007
           70 I                             I+                            I           .041       .007
           72 I                             I+                            I           .041       .012
           74 I                            #I                             I           .017      -.004
           76 I                            #I                             I           .010      -.004
           78 I                             I                             I           .009       .001
           80 I                             I                             I           .003       .000
           82 I                             I                             I           .000       .000
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                 JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                           (Calculated from the bottom of the installation and
              based on the resultant of both the"A" and "B" components of slope change)



                 TILTMETER INSTALLATION:86I1                    DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                                  MM/DD/YYYY    MM/DD/YYYY
           CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION         DATE: 6 12 1986    6 26 1986
DEPTH(FT.)                                                                             +          *
           -1.50     -1.00     -.50       .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                              I+                           I           .026       .023
           4 I                              I+                           I           .028       .032
           6 I                              I                            I           .014       .001
           8 I                              I                            I           .014       .006
          10 I                              I                            I           .011       .004
          12 I                              I                            I           .012       .011
          14 I                              I                            I           .016       .016
          16 I                              I                            I           .017       .031
          18 I                              I                            I           .019       .036
          20 I                              I+                           I           .028       .040
          22 I                              I+                           I           .028       .039
          24 I                              I+                           I           .029       .044
          26 I                              I+                           I           .031       .047
          28 I                              I+                           I           .031       .047
          30 I                              I+                           I           .032       .050
          32 I                              I*                           I           .035       .054
          34 I                              I*                           I           .043       .058
          36 I                              I*                           I           .041       .061
          38 I                              I*                           I           .043       .063
          40 I                              I*                           I           .044       .064
          42 I                              I*                           I           .045       .065
          44 I                              I                            I           .017       .022
          46 I                              I                            I           .016       .020
          48 I                              I                            I           .018       .023
          50 I                              I                            I           .019       .025
          52 I                              I                            I           .022       .026
          54 I                              I                            I           .010       .021
          56 I                              I                            I           .014       .024
          58 I                              I                            I           .015       .025
          60 I                              I                            I           .016       .026
          62 I                              I                            I           .009       .011
          64 I                              I                            I           .008       .010
          66 I                              I                            I           .007       .008
          68 I                              I                            I           .007       .006
          70 I                              I                            I           .007       .004
          72 I                              I                            I           .012       .004
          74 I                              I                            I          -.004       .001
          76 I                              I                            I          -.004       .000
          78 I                              I                            I           .001       .002
          80 I                              I                            I           .000       .001
          82 I                              I                            I           .000       .000
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                 JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING

       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                            (Calculated from the bottom of the installation and
             based on the resultant of both the"A" and "B" components of slope change)


                 TILTMETER INSTALLATION:86I2                 DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY    MM/DD/YYYY
              CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 6 26 1986    7 21 1986
DEPTH(FT.)                                                                          +            *
           -1.50    -1.00     -.50      .00       .50     1.00     1.50
            IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
          2 I                             I *                          I          .023         .171
          4 I                             I+ *                         I          .032         .175
          6 I                             I *                          I          .001         .139
          8 I                             I *                          I          .008         .143
         10 I                             I *                          I          .004         .135
         12 I                             I *                          I          .011         .138
         14 I                             I *                          I          .016         .140
         16 I                             I+*                          I          .031         .144
         18 I                             I+*                          I          .036         .146
         20 I                             I+*                          I          .040         .149
         22 I                             I+*                          I          .039         .145
         24 I                             I+*                          I          .044         .147
         26 I                             I+*                          I          .047         .148
         28 I                             I+*                          I          .047         .144
         30 I                             I+*                          I          .050         .143
         32 I                             I+*                          I          .054         .144
         34 I                             I+*                          I          .058         .145
         36 I                             I+*                          I          .061         .145
         38 I                             I+*                          I          .063         .145
         40 I                             I+*                          I          .064         .143
         42 I                             I+*                          I          .065         .142
         44 I                             I*                           I          .022         .086
         46 I                             I*                           I          .020         .080
         48 I                             I*                           I          .023         .080
         50 I                             I*                           I          .025         .078
         52 I                             I*                           I          .026         .077
         54 I                             I*                           I          .021         .074
         56 I                             I*                           I          .024         .072
         58 I                             I*                           I          .025         .070
         60 I                             I*                           I          .026         .068
         62 I                             I                            I          .011         .048
         64 I                             I                            I          .010         .043
         66 I                             I                            I          .008         .037
         68 I                             I                            I          .006         .032
         70 I                             I                            I          .004         .027
         72 I                             I                            I          .004         .026
         74 I                             I                            I          .001         .015
         76 I                             I                            I          .000         .011
         78 I                             I                            I          .002         .011
         80 I                             I                            I          .001         .006
         82 I                             I                            I          .000         .000
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                  JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING

       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                             (Calculated from the bottom of the installation and
              based on the resultant of both the"A" and "B" components of slope change)


                 TILTMETER INSTALLATION:86I1                    DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:         0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 7 21 1986    7 29 1986
DEPTH(FT.)                                                                           +           *
           -1.50     -1.00      -.50       .00        .50     1.00     1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                             I *+                          I           .171      .112
           4 I                             I * +                         I           .175      .118
           6 I                             I* +                          I           .139      .088
           8 I                             I* +                          I           .143      .095
          10 I                             I* +                          I           .135      .086
          12 I                             I* +                          I           .138      .092
          14 I                             I* +                          I           .140      .097
          16 I                             I *+                          I           .144      .100
          18 I                             I *+                          I           .146      .103
          20 I                             I *+                          I           .149      .106
          22 I                             I *+                          I           .145      .103
          24 I                             I *+                          I           .147      .106
          26 I                             I *+                          I           .148      .107
          28 I                             I *+                          I           .144      .106
          30 I                             I *+                          I           .143      .106
          32 I                             I *+                          I           .144      .109
          34 I                             I *+                          I           .145      .111
          36 I                             I *+                          I           .145      .112
          38 I                             I *+                          I           .145      .113
          40 I                             I *+                          I           .143      .113
          42 I                             I *+                          I           .142      .113
          44 I                             I*+                           I           .086      .058
          46 I                             I*+                           I           .080      .054
          48 I                             I*+                           I           .080      .054
          50 I                             I*+                           I           .078      .053
          52 I                             I*+                           I           .077      .053
          54 I                             I*                            I           .074      .052
          56 I                             I*                            I           .072      .052
          58 I                             I*                            I           .070      .052
          60 I                             I*                            I           .068      .050
          62 I                             I+                            I           .048      .029
          64 I                             I+                            I           .043      .026
          66 I                             I+                            I           .037      .020
          68 I                             I+                            I           .032      .016
          70 I                             I+                            I           .027      .012
          72 I                             I+                            I           .026      .011
          74 I                             I                             I           .015      .007
          76 I                             I                             I           .011      .004
          78 I                             I                             I           .011      .003
          80 I                             I                             I           .006      .001
          82 I                             I                             I           .000      .000
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              JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                              (Calculated from the bottom of the installation and
           based on the resultant of both the"A" and "B" components of slope change)



              TILTMETER INSTALLATION:B611                       DEPTH:   2FT. -  82FT.

              AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                                MM/DD/YYYY    MM/DD/YYYY
           CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 7 29 1986    8  6 1986
DEPTH(FT.)                                                                           *             *
          -1.50    -1.00     -.50       .00      .50     1.00     1.50
           IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
         2 I                            I *                            I          .112          .149
         4 I                            I **                           I          .118          .154
         6 I                            I *                            I          .088          .118
         8 I                            I *                            I          .095          .124
        10 I                            I *                            I          .086          .114
        12 I                            I *                            I          .092          .120
        14 I                            I *                            I          .097          .124
        16 I                            I *                            I          .100          .127
        18 I                            I *                            I          .103          .130
        20 I                            I *                            I          .106          .132
        22 I                            I *                            I          .103          .129
        24 I                            I *                            I          .106          .130
        26 I                            I *                            I          .107          .130
        28 I                            I *                            I          .106          .127
        30 I                            I *                            I          .106          .127
        32 I                            I *                            I          .109          .129
        34 I                            I *                            I          .111          .130
        36 I                            I *                            I          .112          .130
        38 I                            I *                            I          .113          .130
        40 I                            I *                            I          .113          .129
        42 I                            I *                            I          .113          .128
        44 I                            I*                             I          .058          .071
        46 I                            I*                             I          .054          .067
        48 I                            I*                             I          .054          .067
        50 I                            I*                             I          .053          .067
        52 I                            I*                             I          .053          .067
        54 I                            I*                             I          .052          .064
        56 I                            I*                             I          .052          .062
        58 I                            I*                             I          .052          .060
        60 I                            I*                             I          .050          .058
        62 I                            I*                             I          .029          .037
        64 I                            I*                             I          .026          .034
        66 I                            I                              I          .020          .029
        68 I                            I                              I          .016          .023
        70 I                            I                              I          .012          .018
        72 I                            I                              I          .011          .016
        74 I                            I                              I          .007          .011
        76 I                            I                              I          .004          .006
        78 I                            I                              I          .003          .004
        80 I                           *I                              I          .001         -.001
        82 I                            I                              I          .000          .000
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                JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


   CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 1-3 (Perpendicular to slope contours)
                        (Calculated from the bottom of the installation and
          based on the resultant of both the"A" and "B" components of slope change)



                TILTMETER INSTALLATION:8611                    DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:       0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                                MM/DD/YYYY    MM/DD/YYYY
          CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 8  6 1986   8 13 1986
DEPTH(FT.)                                                                           +           *
    -1.50     -1.00     -.50       .00       .50      1.00      1.50
      IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
    2 I                             I *+                          I        .149      .133
    4 I                             I *+                          I        .154      .138
    6 I                             I *                           I        .118      .102
    8 I                             I *                           I        .124      .108
   10 I                             I*+                           I        .114      .097
   12 I                             I *                           I        .120      .103
   14 I                             I *                           I        .124      .100
   16 I                             I *+                          I        .127      .103
   18 I                             I *+                          I        .130      .106
   20 I                             I *+                          I        .132      .107
   22 I                             I *+                          I        .129      .104
   24 I                             I *+                          I        .130      .106
   26 I                             I *+                          I        .130      .107
   28 I                             I *+                          I        .127      .104
   30 I                             I *+                          I        .127      .104
   32 I                             I *+                          I        .129      .107
   34 I                             I *+                          I        .130      .109
   36 I                             I *+                          I        .130      .109
   38 I                             I *+                          I        .130      .109
   40 I                             I *+                          I        .129      .109
   42 I                             I *+                          I        .128      .107
   44 I                             I+                            I        .071      .048
   46 I                             I+                            I        .067      .043
   48 I                             I+                            I        .067      .043
   50 I                             I+                            I        .067      .042
   52 I                             I+                            I        .067      .041
   54 I                             I+                            I        .064      .041
   56 I                             I+                            I        .062      .040
   58 I                             I+                            I        .060      .037
   60 I                             I+                            I        .058      .035
   62 I                             I+                            I        .037      .014
   64 I                             I+                            I        .034      .013
   66 I                             I+                            I        .029      .009
   68 I                             I                             I        .023      .005
   70 I                             I                             I        .018      .001
   72 I                             I                             I        .016      .000
   74 I                             I                             I        .011      .002
   76 I                             I                             I        .006      .001
   78 I                             I                             I        .004      .001
   80 I                             I                             I       -.001      .001
   82 I                             I                             I        .000      .000
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                JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                          (Calculated from the bottom of theinstallation and
            based on the resultant of both the "A" and "B" components of slope change)



                TILTMETER INSTALLATION:8611                    DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                              MM/DD/YYYY    MM/DD/YYYY
             CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION      DATE: 5  8 1986    5 16 1986
DEPTH(FT.)                                                                         +            *
         -1.50     -1.00      -.50       .00       .50      1.00      1.50
          IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
        2 I                             I*                             I         .000        .059
        4 I                             I*                             I         .000        .059
        6 I                             I*                             I         .000        .057
        8 I                             I*                             I         .000        .056
       10 I                             I*                             I         .000        .051
       12 I                             I*                             I         .000        .051
       14 I                             I*                             I         .000        .053
       16 I                             I                              I         .000        .046
       18 I                             I                              I         .000        .046
       20 I                             I                              I         .000        .046
       22 I                             I                              I         .000        .048
       24 I                             I                              I         .000        .049
       26 I                             I*                             I         .000        .051
       28 I                             I*                             I         .000        .052
       30 I                             I                              I         .000        .047
       32 I                             I                              I         .000        .046
       34 I                             I                              I         .000        .044
       36 I                             I                              I         .000        .018
       38 I                             I                              I         .000        .016
       40 I                             I                              I         .000        .011
       42 I                             I                              I         .000        .008
       44 I                             I                              I         .000        .008
       46 I                             I                              I         .000        .008
       48 I                             I                              I         .000        .007
       50 I                             I                              I         .000        .007
       52 I                             I                              I         .000        .004
       54 I                             I                              I         .000        .001
       56 I                             I                              I         .000        .001
       58 I                             I                              I         .000        .002
       60 I                             I                              I         .000        .000
       62 I                            *I                              I         .000       -.003
       64 I                            *I                              I         .000       -.004
       66 I                            *I                              I         .000       -.004
       68 I                            *I                              I         .000       -.003
       70 I                            *I                              I         .000       -.004
       72 I                            *I                              I         .000       -.004
       74 I                            *I                              I         .000       -.001
       76 I                             I                              I         .000        .000
       78 I                             I                              I         .000        .001
       80 I                             I                              I         .000        .001
       82 I                             I                              I         .000        .000
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               JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING

        CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                           (Calculated from the bottom of theinstallation and
           based on the resultant of both the "A" and "B" components of slope change)


               TILTMETER INSTALLATION:8611                    DEPTH:   2FT. -  82FT.

               AZIMUTH OF GROOVE 1-3:        0. DEGREES         INITIAL DATA RECORDED:  5  8 1986

                                                                         MM/DD/YYYY    MM/DD/YYYY
           CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION      DATE: 5 16 1986    5 23 1986
DEPTH(FT.)                                                                     +            *
   -1.50     -1.00     -.50      .00       .50      1.00      1.50
     IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
   2 I                             I*                            I       .059       .088
   4 I                             I*                            I       .059       .086
   6 I                             I*                            I       .057       .082
   8 I                             I*                            I       .056       .077
  10 I                             I*                            I       .051       .070
  12 I                             I*                            I       .051       .067
  14 I                             I*                            I       .053       .065
  16 I                             I*                            I       .046       .059
  18 I                             I*                            I       .046       .058
  20 I                             I*                            I       .046       .055
  22 I                             I*                            I       .048       .052
  24 I                             I*                            I       .049       .056
  26 I                             I*                            I       .051       .055
  28 I                             I*                            I       .052       .052
  30 I                             I+                            I       .047       .046
  32 I                             I+                            I       .046       .041
  34 I                             I+                            I       .044       .038
  36 I                             I                             I       .018       .036
  38 I                             I                             I       .016       .032
  40 I                             I                             I       .011       .032
  42 I                             I                             I       .008       .028
  44 I                             I                             I       .008       .023
  46 I                             I                             I       .008       .023
  48 I                             I                             I       .007       .023
  50 I                             I                             I       .007       .024
  52 I                             I                             I       .004       .022
  54 I                             I                             I       .001       .019
  56 I                             I                             I       .001       .019
  58 I                             I                             I       .002       .016
  60 I                             I                             I       .000       .014
  62 I                             I                             I      -.003       .009
  64 I                             I                             I      -.004       .006
  66 I                             I                             I      -.004       .004
  68 I                             I                             I      -.003       .002
  70 I                             I                             I      -.004       .005
  72 I                             I                             I      -.004       .004
  74 I                             I                             I      -.001       .004
  76 I                             I                             I       .000       .002
  78 I                             I                             I       .001       .001
  80 I                            *I                             I       .001      -.001
  82 I                             I                             I       .000       .000
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                  JOB NUMBER  V603957          LINE CREEK MINE: FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                              (Calculated from the bottom of theinstallation and
             based on the resultant of both the "A" and "B" components of slope change)



                 TILTMETER INSTALLATION:86I1                     DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:        0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                                  MM/DD/YYYY  MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 5 23 1986   5 27 1986
DEPTH(FT.)                                                                           +          #
           -1.50     -1.00      -.50       .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                            #I +                           I          .088      -.001
           4 I                             I +                           I          .086       .001
           6 I                            #I +                           I          .082      -.002
           8 I                            #I +                           I          .077      -.002
          10 I                            #I+                            I          .070      -.005
          12 I                            #I+                            I          .067      -.004
          14 I                            #I+                            I          .065      -.003
          16 I                            #I+                            I          .059      -.007
          18 I                            #I+                            I          .058      -.007
          20 I                            #I+                            I          .055      -.007
          22 I                            #I+                            I          .052      -.008
          24 I                            #I+                            I          .056      -.005
          26 I                            #I+                            I          .055      -.002
          28 I                            #I+                            I          .052      -.001
          30 I                            #I+                            I          .046      -.006
          32 I                            #I+                            I          .041      -.007
          34 I                            #I+                            I          .038      -.011
          36 I                            #I+                            I          .036      -.010
          38 I                            #I+                            I          .032      -.010
          40 I                            #I+                            I          .032      -.011
          42 I                            #I+                            I          .028      -.013
          44 I                            #I                             I          .023      -.011
          46 I                            #I                             I          .023      -.010
          48 I                            #I                             I          .023      -.009
          50 I                            #I                             I          .024      -.006
          52 I                            #I                             I          .022      -.007
          54 I                            #I                             I          .019      -.006
          56 I                            #I                             I          .019      -.003
          58 I                            #I                             I          .016      -.003
          60 I                            #I                             I          .014      -.002
          62 I                            #I                             I          .009      -.007
          64 I                            #I                             I          .006      -.006
          66 I                            #I                             I          .004      -.007
          68 I                            #I                             I          .002      -.008
          70 I                            #I                             I          .005      -.007
          72 I                            #I                             I          .004      -.005
          74 I                            #I                             I          .004      -.004
          76 I                            #I                             I          .002      -.002
          78 I                            #I                             I          .001      -.001
          80 I                            #I                             I         -.001      -.001
          82 I                             I                             I          .000       .000
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                  JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                      (Calculated from the bottom of theinstallation and
          based on the resultant of both the "A" and "B" components of slope change)



                TILTMETER INSTALLATION:8611                DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:      0. DEGREES        INITIAL DATA RECORDED:  5  8 1986

                                                                          MM/DD/YYYY    MM/DD/YYYY
          CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 5 27 1986    5 30 1986
DEPTH(FT.)                                                                    +            *
           -1.50     -1.00     -.50      .00       .50      1.00     1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
          2 I                           I                             I         -.001        .020
          4 I                           I                             I          .001        .023
          6 I                           I                             I         -.002        .019
          8 I                           I                             I         -.002        .019
         10 I                           I                             I         -.005        .016
         12 I                           I                             I         -.004        .017
         14 I                           I                             I         -.003        .016
         16 I                           I                             I         -.007        .012
         18 I                           I                             I         -.007        .012
         20 I                           I                             I         -.007        .011
         22 I                           I                             I         -.008        .010
         24 I                           I                             I         -.005        .009
         26 I                           I                             I         -.002        .010
         28 I                           I                             I         -.001        .011
         30 I                           I                             I         -.006        .007
         32 I                           I                             I         -.007        .004
         34 I                           I                             I         -.011        .003
         36 I                           I                             I         -.010        .004
         38 I                           I                             I         -.010        .002
         40 I                           I                             I         -.011        .002
         42 I                           I                             I         -.013        .001
         44 I                          *I                             I         -.011       -.004
         46 I                          *I                             I         -.010       -.005
         48 I                          *I                             I         -.009       -.004
         50 I                          *I                             I         -.006       -.002
         52 I                          *I                             I         -.007       -.004
         54 I                          *I                             I         -.006       -.004
         56 I                          *I                             I         -.003       -.004
         58 I                          *I                             I         -.003       -.005
         60 I                          *I                             I         -.002       -.004
         62 I                          *I                             I         -.007       -.010
         64 I                          *I                             I         -.006       -.011
         66 I                          *I                             I         -.007       -.011
         68 I                          *I                             I         -.008       -.011
         70 I                          *I                             I         -.007       -.010
         72 I                          *I                             I         -.005       -.010
         74 I                          *I                             I         -.004       -.002
         76 I                          *I                             I         -.002       -.002
         78 I                          *I                             I         -.001       -.002
         80 I                          *I                             I         -.001       -.002
         82 I                           I                             I          .000        .000
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                 JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                          (Calculated from the bottom of theinstallation and
            based on the resultant of both the "A" and "B" components of slope change)



                TILTMETER INSTALLATION:86I1                      DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:        0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                                MM/DD/YYYY    MM/DD/YYYY
             CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 5 30 1986    6  4 1986
DEPTH(FT.)                                                                          *             #
          -1.50     -1.00      -.50       .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                              I*                             I          .020         .076
           4 I                              I*                             I          .023         .075
           6 I                              I*                             I          .019         .064
           8 I                              I*                             I          .019         .061
          10 I                              I*                             I          .016         .053
          12 I                              I*                             I          .017         .053
          14 I                              I                              I          .016         .049
          16 I                              I                              I          .012         .042
          18 I                              I                              I          .012         .043
          20 I                              I                              I          .011         .041
          22 I                              I                              I          .010         .038
          24 I                              I                              I          .009         .038
          26 I                              I                              I          .010         .038
          28 I                              I                              I          .011         .039
          30 I                              I                              I          .007         .034
          32 I                              I                              I          .004         .031
          34 I                              I                              I          .003         .029
          36 I                              I                              I          .004         .026
          38 I                              I                              I          .002         .020
          40 I                              I                              I          .002         .019
          42 I                              I                              I          .001         .016
          44 I                              I                              I         -.004         .016
          46 I                              I                              I         -.005         .016
          48 I                              I                              I         -.004         .014
          50 I                              I                              I         -.002         .013
          52 I                              I                              I         -.004         .011
          54 I                              I                              I         -.004         .011
          56 I                              I                              I         -.004         .012
          58 I                              I                              I         -.005         .010
          60 I                              I                              I         -.004         .008
          62 I                              I                              I         -.010         .002
          64 I                              I                              I         -.011         .000
          66 I                             *I                              I         -.011        -.001
          68 I                             *I                              I         -.011        -.002
          70 I                             *I                              I         -.010        -.002
          72 I                             *I                              I         -.010        -.005
          74 I                              I                              I         -.002         .000
          76 I                             *I                              I         -.002        -.001
          78 I                             *I                              I         -.002        -.001
          80 I                             *I                              I         -.002        -.001
          82 I                              I                              I          .000         .000
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              JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


       CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                          (Calculated from the bottom of theinstallation and
              based on the resultant of both the "A" and "B" components of slope change)



              TILTMETER INSTALLATION:86I                       DEPTH:   2FT. -  82FT.

              AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                          MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION     DATE: 6  4 1986    6  9 1986
DEPTH(FT.)                                                                     +             *
        -1.50     -1.00      -.50       .00       .50      1.00      1.50
          IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
        2 I                            I +                           I          .076          .001
        4 I                            I +                           I          .075          .001
        6 I                           *I+                            I          .064         -.005
        8 I                           *I+                            I          .061         -.009
       10 I                           *I+                            I          .053         -.017
       12 I                           *I+                            I          .053         -.017
       14 I                           *I+                            I          .049         -.017
       16 I                           *I+                            I          .042         -.020
       18 I                           *I+                            I          .043         -.019
       20 I                           *I+                            I          .041         -.020
       22 I                           *I+                            I          .038         -.022
       24 I                           *I+                            I          .038         -.023
       26 I                           *I+                            I          .038         -.022
       28 I                           *I+                            I          .039         -.020
       30 I                           *I+                            I          .034         -.023
       32 I                           *I+                            I          .031         -.023
       34 I                           *I+                            I          .029         -.024
       36 I                           *I+                            I          .026         -.022
       38 I                           *I                             I          .020         -.019
       40 I                           *I                             I          .019         -.014
       42 I                           *I                             I          .016         -.014
       44 I                           *I                             I          .016         -.024
       46 I                           *I                             I          .016         -.023
       48 I                           *I                             I          .014         -.019
       50 I                           *I                             I          .013         -.014
       52 I                           *I                             I          .011         -.014
       54 I                           *I                             I          .011         -.017
       56 I                           *I                             I          .012         -.017
       58 I                           *I                             I          .010         -.019
       60 I                           *I                             I          .008         -.023
       62 I                           *I                             I          .002         -.038
       64 I                           *I                             I          .000         -.025
       66 I                           *I                             I         -.001         -.022
       68 I                           *I                             I         -.002         -.017
       70 I                           *I                             I         -.002         -.012
       72 I                           *I                             I         -.005         -.012
       74 I                            I                             I          .000          .005
       76 I                            I                             I         -.001          .005
       78 I                            I                             I         -.001          .005
       80 I                            I                             I         -.001          .005
       82 I                            I                             I          .000          .000
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                 JOB NUMBER  V603957         LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                               (Calculated from the bottom of theinstallation and
             based on the resultant of both the "A" and "B" components of slope change)



                TILTMETER INSTALLATION:86I1                    DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:       0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                               MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 6  9 1986    6 12 1986
DEPTH(FT.)                                                                        +           *
           -1.50     -1.00      -.50       .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                             I*                            I            .001       .070
           4 I                             I*                            I            .001       .070
           6 I                             I*                            I           -.005       .061
           8 I                             I*                            I           -.009       .053
          10 I                             I                             I           -.017       .041
          12 I                             I                             I           -.017       .040
          14 I                             I                             I           -.017       .041
          16 I                             I                             I           -.020       .038
          18 I                             I                             I           -.019       .040
          20 I                             I                             I           -.020       .038
          22 I                             I                             I           -.022       .036
          24 I                             I                             I           -.023       .032
          26 I                             I                             I           -.022       .031
          28 I                             I                             I           -.020       .029
          30 I                             I                             I           -.023       .023
          32 I                             I                             I           -.023       .022
          34 I                             I                             I           -.024       .021
          36 I                             I                             I           -.022       .022
          38 I                             I                             I           -.019       .025
          40 I                             I                             I           -.014       .026
          42 I                             I                             I           -.014       .026
          44 I                             I                             I           -.024       .013
          46 I                             I                             I           -.023       .012
          48 I                             I                             I           -.019       .014
          50 I                             I                             I           -.014       .018
          52 I                             I                             I           -.014       .016
          54 I                             I                             I           -.017       .012
          56 I                             I                             I           -.017       .013
          58 I                             I                             I           -.019       .013
          60 I                             I                             I           -.023       .009
          62 I                            *I                             I           -.038      -.008
          64 I                            *I                             I           -.025      -.001
          66 I                            *I                             I           -.022      -.001
          68 I                            *I                             I           -.017      -.001
          70 I                            *I                             I           -.012      -.001
          72 I                            *I                             I           -.012      -.004
          74 I                             I                             I            .005       .007
          76 I                             I                             I            .005       .007
          78 I                             I                             I            .005       .006
          80 I                             I                             I            .005       .003
          82 I                             I                             I            .000       .000
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                  JOB NUMBER  VG03957           LINE CREEK MINE:  FOOTWALL MONITORING

      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                              (Calculated from the bottom of theinstallation and
             based on the resultant of both the "A" and "B" components of slope change)


                 TILTMETER INSTALLATION:86I1                    DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:       0. DEGREES            INITIAL DATA RECORDED:  5  8 1986

                                                                                  MM/DD/YYYY MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 6 12 1986    6 26 1986
DEPTH(FT.)                                                                           +          *
           -1.50     -1.00      -.50       .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                             I+                            I           .070       .045
           4 I                             I+                            I           .070       .049
           6 I                             I+                            I           .061       .045
           8 I                             I+                            I           .053       .044
          10 I                             I+                            I           .041       .031
          12 I                             I+                            I           .040       .031
          14 I                             I+                            I           .041       .027
          16 I                             I+                            I           .038       .031
          18 I                             I+                            I           .040       .031
          20 I                             I+                            I           .038       .030
          22 I                             I+                            I           .036       .029
          24 I                             I+                            I           .032       .034
          26 I                             I+                            I           .031       .034
          28 I                             I+                            I           .029       .034
          30 I                             I                             I           .023       .028
          32 I                             I                             I           .022       .026
          34 I                             I                             I           .021       .023
          36 I                             I                             I           .022       .019
          38 I                             I+                            I           .025       .017
          40 I                             I+                            I           .026       .016
          42 I                             I+                            I           .026       .016
          44 I                             I                             I           .013       .012
          46 I                             I                             I           .012       .011
          48 I                             I                             I           .014       .011
          50 I                             I                             I           .018       .011
          52 I                             I                             I           .016       .011
          54 I                             I                             I           .012       .011
          56 I                             I                             I           .013       .013
          58 I                             I                             I           .013       .014
          60 I                             I                             I           .009       .015
          62 I                             I                             I          -.008       .006
          64 I                             I                             I          -.001       .007
          66 I                             I                             I          -.001       .004
          68 I                             I                             I          -.001       .004
          70 I                             I                             I          -.001       .002
          72 I                             I                             I          -.004       .001
          74 I                             I                             I           .007       .005
          76 I                             I                             I           .007       .005
          78 I                             I                             I           .006       .005
          80 I                             I                             I           .003       .004
          82 I                             I                             I           .000       .000
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                  JOB NUMBER  V603957           LINE CREEK MINE:  FOOTWALL MONITORING

      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                              (Calculated from the bottom of theinstallation and
             based on the resultant of both the "A" and "B" components of slope change)


                 TILTMETER INSTALLATION:86I2                    DEPTH:   2FT. -  82FT.

                 AZIMUTH OF GROOVE 1-3:       0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY    MM/DD/YYYY
            CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 6 26 1986   7 21 1986
DEPTH(FT.)                                                                           +          *
           -1.50     -1.00     -.50        .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                             I+                            I           .045       .025
           4 I                             I+                            I           .049       .029
           6 I                             I+                            I           .045       .025
           8 I                             I+                            I           .044       .028
          10 I                             I+                            I           .031       .011
          12 I                             I+                            I           .031       .014
          14 I                             I+                            I           .027       .011
          16 I                             I+                            I           .031       .007
          18 I                             I+                            I           .031       .008
          20 I                             I+                            I           .030       .008
          22 I                             I+                            I           .029       .008
          24 I                             I+                            I           .034       .010
          26 I                             I+                            I           .034       .013
          28 I                             I+                            I           .034       .017
          30 I                             I+                            I           .028       .014
          32 I                             I+                            I           .026       .014
          34 I                             I                             I           .023       .010
          36 I                             I                             I           .019       .007
          38 I                             I                             I           .017       .005
          40 I                             I                             I           .016       .003
          42 I                             I                             I           .016       .003
          44 I                            *I                             I           .012      -.006
          46 I                            *I                             I           .011      -.009
          48 I                            *I                             I           .011      -.010
          50 I                            *I                             I           .011      -.009
          52 I                            *I                             I           .011      -.010
          54 I                            *I                             I           .011      -.009
          56 I                            *I                             I           .013      -.005
          58 I                            *I                             I           .014      -.003
          60 I                             I                             I           .015       .000
          62 I                            *I                             I           .006      -.011
          64 I                            *I                             I           .007      -.010
          66 I                            *I                             I           .004      -.010
          68 I                            *I                             I           .004      -.008
          70 I                            *I                             I           .002      -.006
          72 I                            *I                             I           .001      -.006
          74 I                             I                             I           .005       .002
          76 I                             I                             I           .005       .004
          78 I                             I                             I           .005       .007
          80 I                             I                             I           .004       .007
          82 I                             I                             I           .000       .000
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                JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                            (Calculated from the bottom of theinstallation and
             based on the resultant of both the "A" and "B" components of slope change)



                TILTMETER INSTALLATION:86I1                 DEPTH:   2FT. -  82FT.

                AZIMUTH OF GROOVE 1-3:       0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                                 MM/DD/YYYY   MM/DD/YYYY
           CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 7 21 1986    7 29 1986
DEPTH(FT.)                                                                          +           *
           -1.50     -1.00      -.50       .00       .50      1.00      1.50
             IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
           2 I                             I+*                           I           .025       .102
           4 I                             I+*                           I           .029       .101
           6 I                             I*                            I           .025       .096
           8 I                             I*                            I           .028       .094
          10 I                             I*                            I           .011       .078
          12 I                             I*                            I           .014       .080
          14 I                             I*                            I           .011       .080
          16 I                             I*                            I           .007       .074
          18 I                             I*                            I           .008       .074
          20 I                             I*                            I           .008       .071
          22 I                             I*                            I           .008       .068
          24 I                             I*                            I           .010       .069
          26 I                             I*                            I           .013       .069
          28 I                             I*                            I           .017       .070
          30 I                             I*                            I           .014       .065
          32 I                             I*                            I           .014       .062
          34 I                             I*                            I           .010       .056
          36 I                             I*                            I           .007       .053
          38 I                             I                             I           .005       .049
          40 I                             I                             I           .003       .045
          42 I                             I                             I           .003       .043
          44 I                             I                             I          -.006       .034
          46 I                             I                             I          -.009       .033
          48 I                             I                             I          -.010       .033
          50 I                             I                             I          -.009       .032
          52 I                             I                             I          -.010       .029
          54 I                             I                             I          -.009       .028
          56 I                             I                             I          -.005       .032
          58 I                             I                             I          -.003       .033
          60 I                             I                             I           .000       .033
          62 I                             I                             I          -.011       .019
          64 I                             I                             I          -.010       .017
          66 I                             I                             I          -.010       .015
          68 I                             I                             I          -.008       .013
          70 I                             I                             I          -.006       .011
          72 I                             I                             I          -.006       .008
          74 I                             I                             I           .002       .011
          76 I                             I                             I           .004       .011
          78 I                             I                             I           .007       .010
          80 I                             I                             I           .007       .007
          82 I                             I                             I           .000       .000
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             JOB NUMBER  VG03957          LINE CREEK MINE:  FOOTWALL MONITORING


     CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                          (Calculated from the bottom of theinstallation and
          based on the resultant of both the "A" and "B" components of slope change)



            TILTMETER INSTALLATION:B6I1                    DEPTH:   2FT. -  82FT.

            AZIMUTH OF GROOVE 1-3:       0. DEGREES           INITIAL DATA RECORDED:  5  8 1986

                                                                       MM/DD/YYYY    MM/DD/YYYY
           CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION       DATE: 7 29 1986    8  6 1986
DEPTH(FT.)                                                                      +             #
       -1.50     -1.00      -.50       .00       .50     1.00     1.50
         IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
       2 I                         I #                      I         .102          .105
       4 I                         I #                      I         .101          .109
       6 I                         I #                      I         .096          .108
       8 I                         I #                      I         .094          .107
      10 I                         I#+                      I         .078          .091
      12 I                         I#+                      I         .080          .091
      14 I                         I#+                      I         .080          .092
      16 I                         I#                       I         .074          .087
      18 I                         I#                       I         .074          .087
      20 I                         I#                       I         .071          .086
      22 I                         I#                       I         .068          .082
      24 I                         I#                       I         .069          .083
      26 I                         I#                       I         .069          .082
      28 I                         I#                       I         .070          .080
      30 I                         I#                       I         .065          .075
      32 I                         I#                       I         .062          .073
      34 I                         I#                       I         .056          .066
      36 I                         I#                       I         .053          .065
      38 I                         I#                       I         .049          .059
      40 I                         I#                       I         .045          .057
      42 I                         I#                       I         .043          .055
      44 I                         I+                       I         .034          .040
      46 I                         I+                       I         .033          .038
      48 I                         I+                       I         .033          .037
      50 I                         I+                       I         .032          .040
      52 I                         I+                       I         .029          .040
      54 I                         I+                       I         .028          .038
      56 I                         I+                       I         .032          .038
      58 I                         I+                       I         .033          .035
      60 I                         I+                       I         .033          .032
      62 I                         I                        I         .019          .019
      64 I                         I                        I         .017          .022
      66 I                         I                        I         .015          .019
      68 I                         I                        I         .013          .015
      70 I                         I                        I         .011          .013
      72 I                         I                        I         .008          .011
      74 I                         I                        I         .011          .014
      76 I                         I                        I         .011          .015
      78 I                         I                        I         .010          .013
      80 I                         I                        I         .007          .008
      82 I                         I                        I         .000          .000
```

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                JOB NUMBER  V603957          LINE CREEK MINE:  FOOTWALL MONITORING


      CUMULATIVE DEFLECTION OF TILTMETER CASING, GROOVE 2-4 (Parallel to slope contours)
                            (Calculated from the bottom of theinstallation and
           based on the resultant of both the "A" and "B" components of slope change)



                  TILTMETER INSTALLATION:86I1                       DEPTH:   2FT. -  82FT.

                  AZIMUTH OF GROOVE 1-3:        0. DEGREES          INITIAL DATA RECORDED:  5  8 1986

                                                                               MM/DD/YYYY   MM/DD/YYYY
             CUMULATIVE DEFLECTION (INCHES) FROM ORIGINAL POSITION        DATE: 8  6 1986    8 13 1986
 DEPTH(FT.)                                                                        +            *
          -1.50     -1.00     -.50      .00       .50      1.00      1.50
            IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
          2 I                          *I +                          I           .105         -.010
          4 I                          *I +                          I           .109         -.011
          6 I                          *I +                          I           .108         -.014
          8 I                          *I +                          I           .107         -.017
         10 I                          *I +                          I           .091         -.037
         12 I                          *I +                          I           .091         -.037
         14 I                          *I +                          I           .092         -.038
         16 I                          *I +                          I           .087         -.044
         18 I                          *I +                          I           .087         -.044
         20 I                          *I +                          I           .086         -.046
         22 I                          *I +                          I           .082         -.049
         24 I                         * I +                          I           .083         -.050
         26 I                         * I +                          I           .082         -.050
         28 I                         * I +                          I           .080         -.052
         30 I                         * I +                          I           .075         -.058
         32 I                         * I+                           I           .073         -.061
         34 I                         * I+                           I           .066         -.063
         36 I                         * I+                           I           .065         -.068
         38 I                         * I+                           I           .059         -.073
         40 I                         * I+                           I           .057         -.076
         42 I                           I+                           I           .055          .043
         44 I                           I+                           I           .040          .032
         46 I                           I+                           I           .038          .031
         48 I                           I+                           I           .037          .030
         50 I                           I+                           I           .040          .030
         52 I                           I+                           I           .040          .027
         54 I                           I+                           I           .038          .027
         56 I                           I+                           I           .038          .028
         58 I                           I+                           I           .035          .026
         60 I                           I+                           I           .032          .025
         62 I                           I                            I           .019          .014
         64 I                           I                            I           .022          .014
         66 I                           I                            I           .017          .011
         68 I                           I                            I           .015          .008
         70 I                           I                            I           .013          .004
         72 I                           I                            I           .011          .002
         74 I                           I                            I           .014          .004
         76 I                           I                            I           .015          .004
         78 I                           I                            I           .013          .005
         80 I                           I                            I           .008          .002
         82 I                           I                            I           .000          .000
```
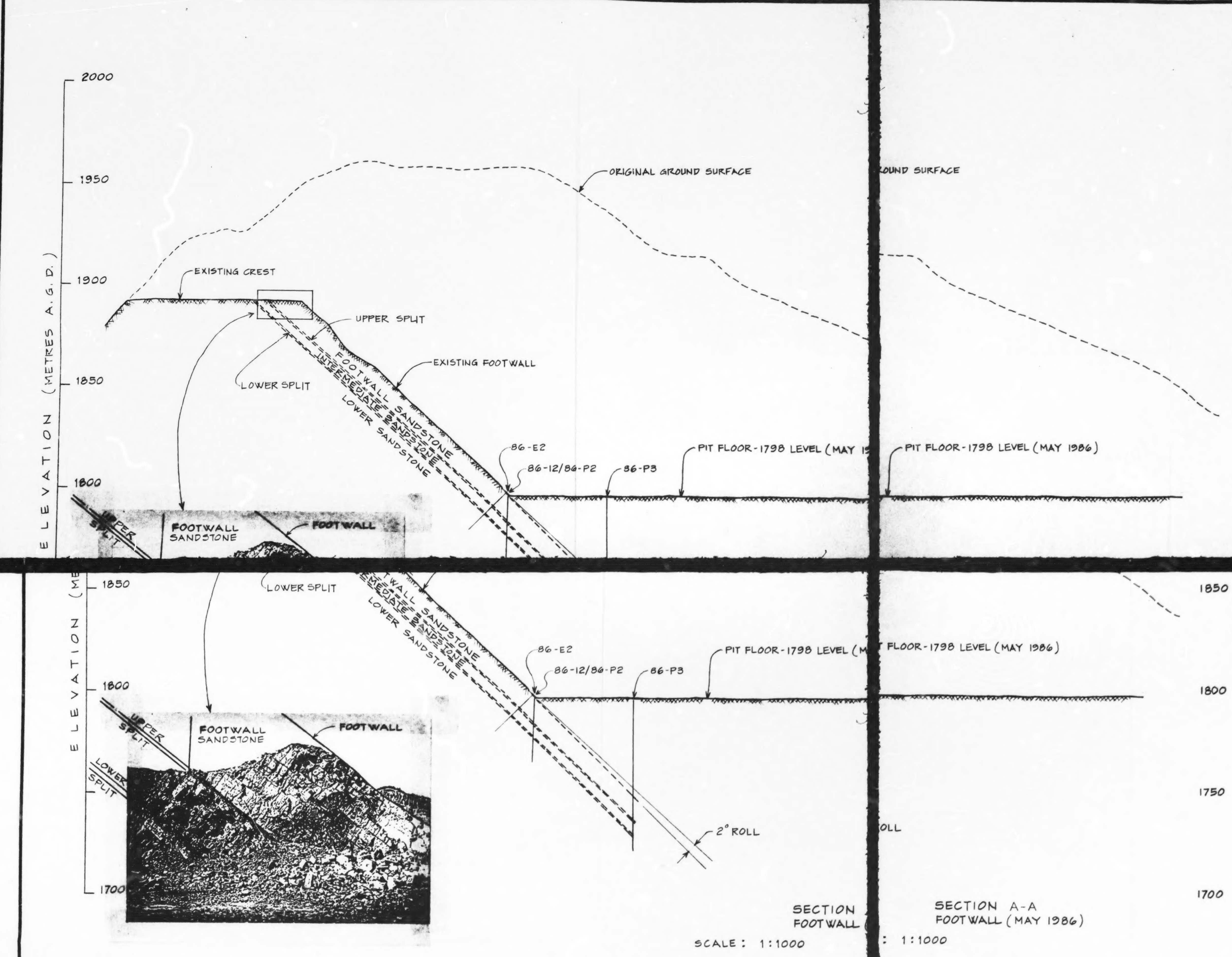
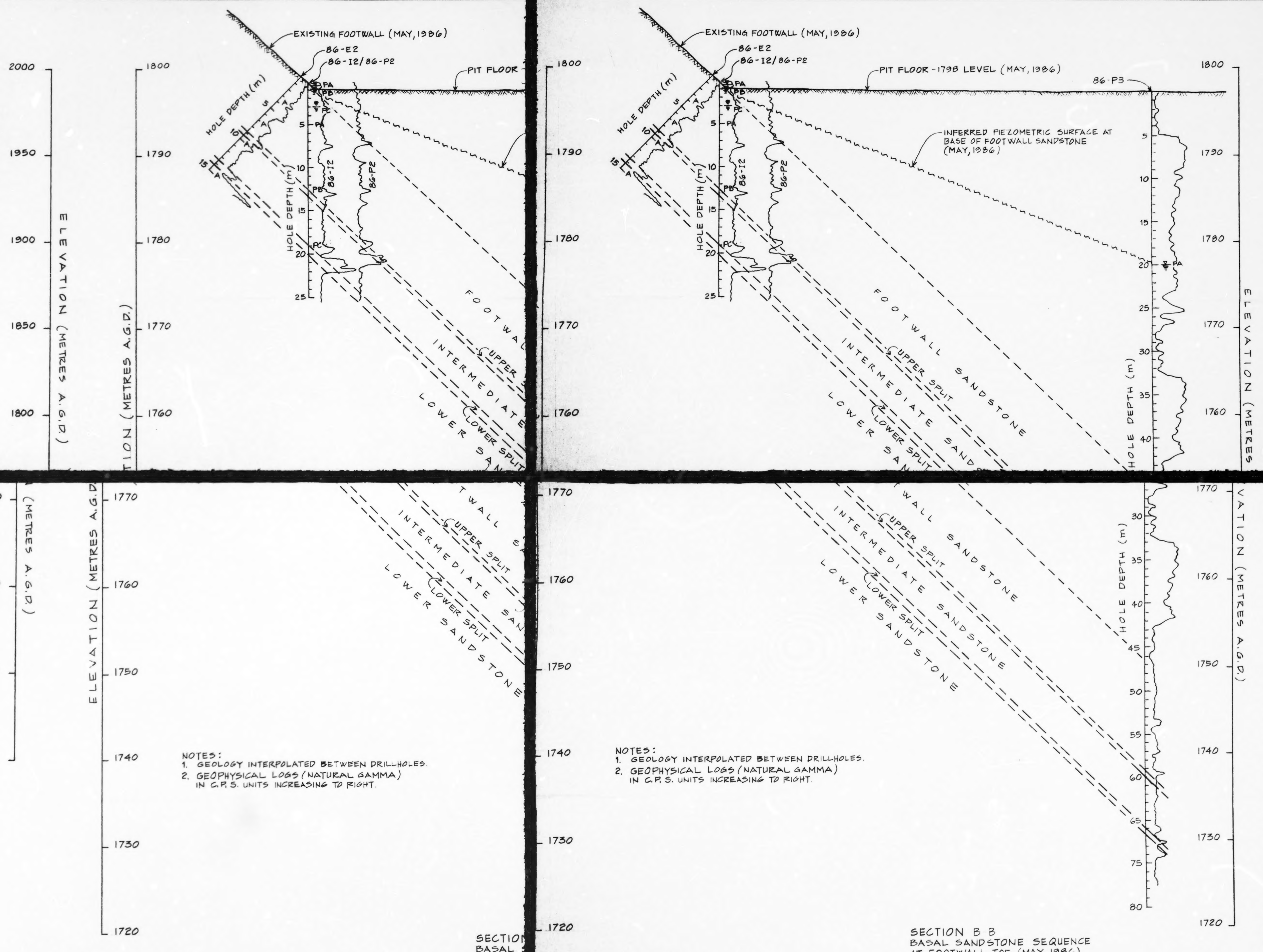

1786 BENCH
1798 BENCH
E
E
5533800N
C
D
C
86-S1,E1,P1,I1
86-GN
86-GC
B
B
86-P2,E2,T2
86-P3
86-GS
D
A
A
APRIL 29 '86
LEGEND
86-E1 INVESTIGATION HOLE NUMBER
B B LINE OF SECTION (SEE FIGURE 6-3)


ELEVATION (METRES A.G.D.)
2000
1950
1900
1850
1800
1700
ORIGINAL GROUND SURFACE
EXISTING CREST
UPPER SPLIT
LOWER SPLIT
EXISTING FOOTWALL
FOOTWALL SANDSTONE
INTERMEDIATE SANDSTONE
LOWER SANDSTONE
86-E2
86-12/86-P2
86-P3
PIT FLOOR - 1798 LEVEL (MAY 1986)
FOOTWALL SANDSTONE
FOOTWALL
UPPER SPLIT
LOWER SPLIT
2° ROLL

SECTION A-A
FOOTWALL (MAY 1986)

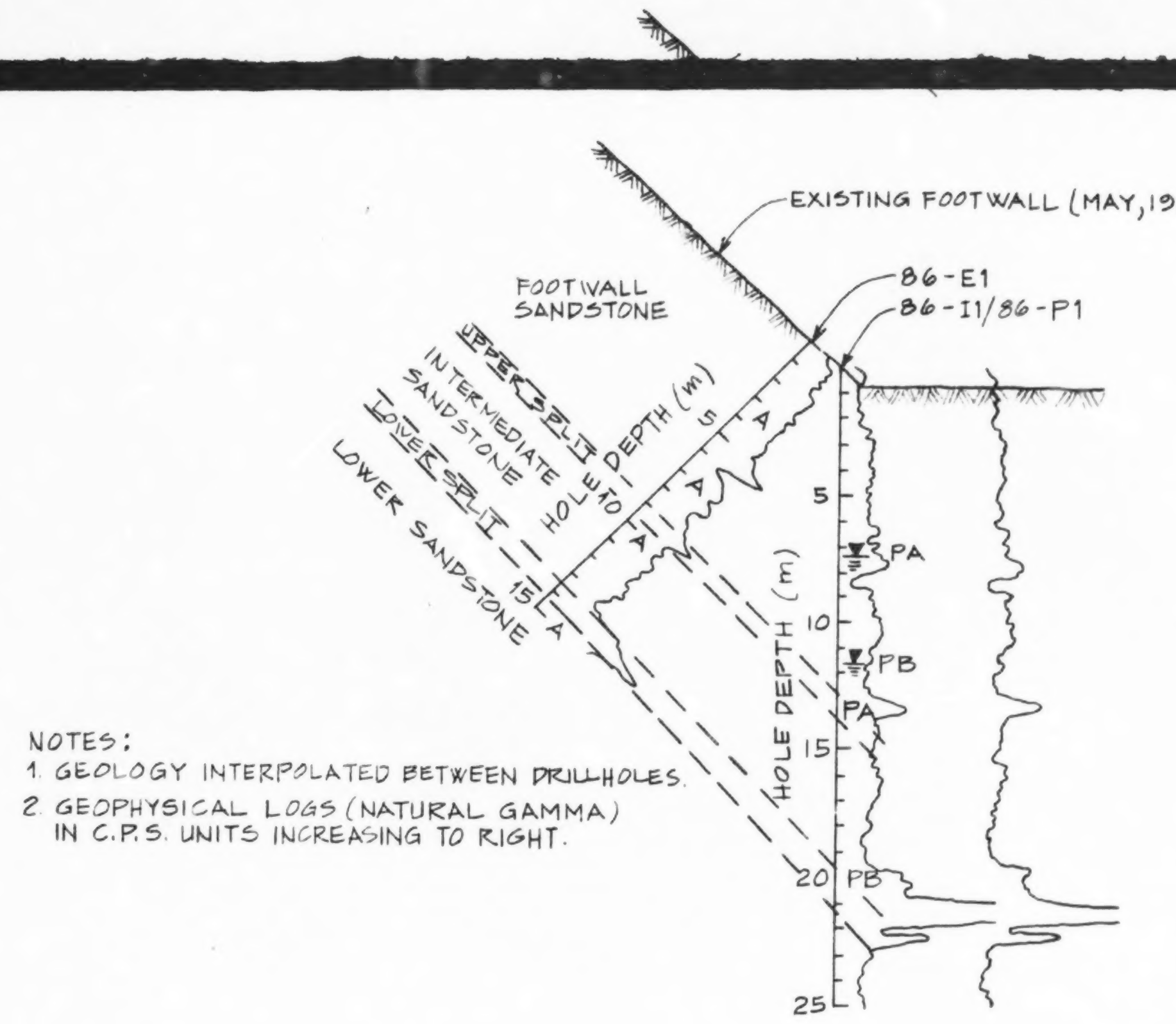
SCALE: 1:1000


ELEVATION (METRES A.G.D.)
1800
1790
1780
1770
1760
1750
1740
1730
1720
EXISTING FOOTWALL (MAY, 1986)
86-E2
86-12/86-P2
PIT FLOOR - 1798 LEVEL (MAY, 1986)
86-P3
HOLE DEPTH (m)
PA
PB
PC
INFERRED PIEZOMETRIC SURFACE AT BASE OF FOOTWALL SANDSTONE (MAY, 1986)
FOOTWALL SANDSTONE
UPPER SPLIT
INTERMEDIATE SANDSTONE
LOWER SPLIT
LOWER SANDSTONE

NOTES:
1. GEOLOGY INTERPOLATED BETWEEN DRILLHOLES.
2. GEOPHYSICAL LOGS (NATURAL GAMMA) IN C.P.S. UNITS INCREASING TO RIGHT.

SECTION B-B
BASAL SANDSTONE SEQUENCE
AT FOOTWALL TOE (MAY, 1986)

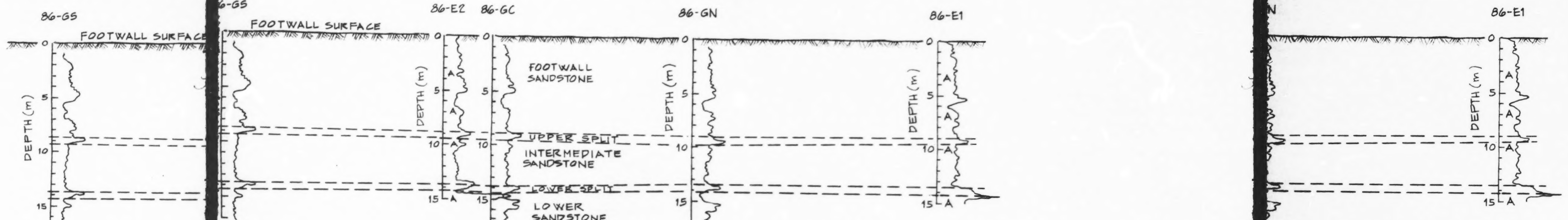
SCALE: 1:200


EXISTING FOOTWALL (MAY, 1986)
86-E1
86-11/86-P1
FOOTWALL SANDSTONE
UPPER SPLIT
INTERMEDIATE SANDSTONE
LOWER SPLIT
LOWER SANDSTONE
HOLE DEPTH (m)
PA
PB
PC

NOTES:
1. GEOLOGY INTERPOLATED BETWEEN DRILLHOLES
2. GEOPHYSICAL LOGS (NATURAL GAMMA) IN C.P.S. UNITS INCREASING TO RIGHT.

SECTION C-C
BASAL SANDSTONE SEQUENCE
AT FOOTWALL TOE (MAY, 1986)

SCALE: 1:200


86-G5
FOOTWALL SURFACE
86-E2
86-GC
86-GN
86-E1
DEPTH (m)
FOOTWALL SANDSTONE
UPPER SPLIT
INTERMEDIATE SANDSTONE
LOWER SPLIT
LOWER SANDSTONE
A

NOTES:
1. GEOLOGY INTERPOLATED AND EXTRAPOLATED FROM 86-E1 AND 86-E2, BASED ON GEOPHYSICAL DATA.
2. GEOPHYSICAL LOGS (NATURAL GAMMA) IN C.P.S. UNITS INCREASING TO RIGHT.
3. SECTION INCLINED 45° TO VERTICAL, INTO FOOTWALL (I.E. PERPENDICULAR TO FOOTWALL SURFACE)

INCLINED SECTION D-D
BASAL SANDSTONE SEQUENCE
PARALLEL TO FOOTWALL

SCALE: HORIZONTAL 1:500
VERTICAL 1:200

LEGEND:

A	ANCHOR POINT FOR EXTENSOMETER
PA	PIEZOMETER LOCATION (WITH IDENTIFIER)
▽PA	PIEZOMETRIC LEVEL FOR APPROPRIATE PIEZOMETER (MAY, 1986)

No.	REVISION	DATE	BY

REFERENCES

HARDY ASSOCIATES (1978) LTD.
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

FIGURE 6-3
SELECTED SECTIONS-LINE CREEK MINE

SCALE AS SHOWN DATE 09/86 MADE ______ CKHD GJB APPD DSC

No. VG03957 REV.

HT27 - 79/06